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NEW ENGLAND INTERCOLLEGIATE GEOLOGICAL CONFERENCE

GUIDEBOOK

for field trips in

Central New Hampshire and

Contiguous Areas

John B. Lyons
Glenn W. Stewart

Editors

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Concord, New Hampshire

Conference Organization

Herbert Tischler
Glenn W. Stewart
John B. Lyons
Dabney M. Caldwell, Secretary, New England Intercollegiate Geological Conference

Field Trip Leaders

Franz E. Anderson, University of New Hampshire, Durham, N.H.
Wallace A. Bothner, University of New Hampshire, Durham, N.H.
Russell G. Clark, Dartmouth College, Hanover, N.H.
Evan Englund, Dartmouth College, Hanover, N. H.
Henri E. Gaudette, University of New Hampshire, Durham, N.H.
Richard P. Goldthwait, Ohio State University, Columbus, Ohio
Robert C. Greene, U.S. Geological Survey, Menlo Park, Calif.
Carl Koteff, U.S. Geological Survey, Boston, Mass.
John B. Lyons, Dartmouth College, Hanover, N. H.
Richard S. Naylor, Massachusetts Institute of Technology, Cambridge, Mass.
Lincoln R. Page, U.S. Geological Survey, Boston, Mass.
Douglas Rumble III, University of California, Los Angeles, Calif.
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John B. Lyons, Dartmouth College, Hanover, N.H.
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FOWARD

The purpose of the New England Intercollegiate Geological Conferences is to provide a field demonstration of work recently completed or currently in progress, primarily for the purpose of encouraging an exchange of ideas. We hope that the 63rd Annual Meeting will be stimulating in this respect.

Commencing with Billings' classic paper on the Littleton-Moosilauke area in 1937, the modern era has witnessed a vast effusion of literature on all aspects of the geology of New Hampshire culminating during 1951-1956 in a 3-volume summary, The Geology of New Hampshire; Part I Surficial Geology by J. W., L., and R. P. Goldthwait; Part II, Bedrock Geology by M. P. Billings; Part III Minerals and Mines by T. R. Meyers and G. W. Stewart. An up-dating and re-interpretation of the geology of New Hampshire is one of the major themes of the 1968 Studies of Appalachian Geology, Northern and Maritime, edited by E-an Zen, W. S. White, J. B. Hadley, and J. B. Thompson, Jr. It would seem that with all the attention, time and talent lavished upon New Hampshire its geological problems should largely be solved. If this Conference does nothing else, it should dispel that illusion.

The 1951 summary of the surficial geology of New Hampshire by the Goldthwaits was based upon reconnaissance studies covering the entire state, with detailed mapping along major valleys. Groundwater problems served as the impetus for surficial mapping in parts of southeastern New Hampshire by Edward Bradley (1964, U.S. Geological Survey Water-Supply Paper 1695), and till fabric studies have been carried out in the central part of the state by L. D. Drake (1968, Ph.D. Dissertation, Ohio State University). However, careful quadrangle-by-quadrangle investigations of glacial and surficial geology are just commencing in New Hampshire. Two of the 1971 NEIGC excursions (Trips A-1 by Goldthwait and B-4 by Koteff and Stone) will explore the progress made to date in refining our understanding of Quaternary history. Important by-products of these studies are an assessment of the State's major mineral resource, sand and gravel, and a better understanding of its rapidly mounting groundwater problems.

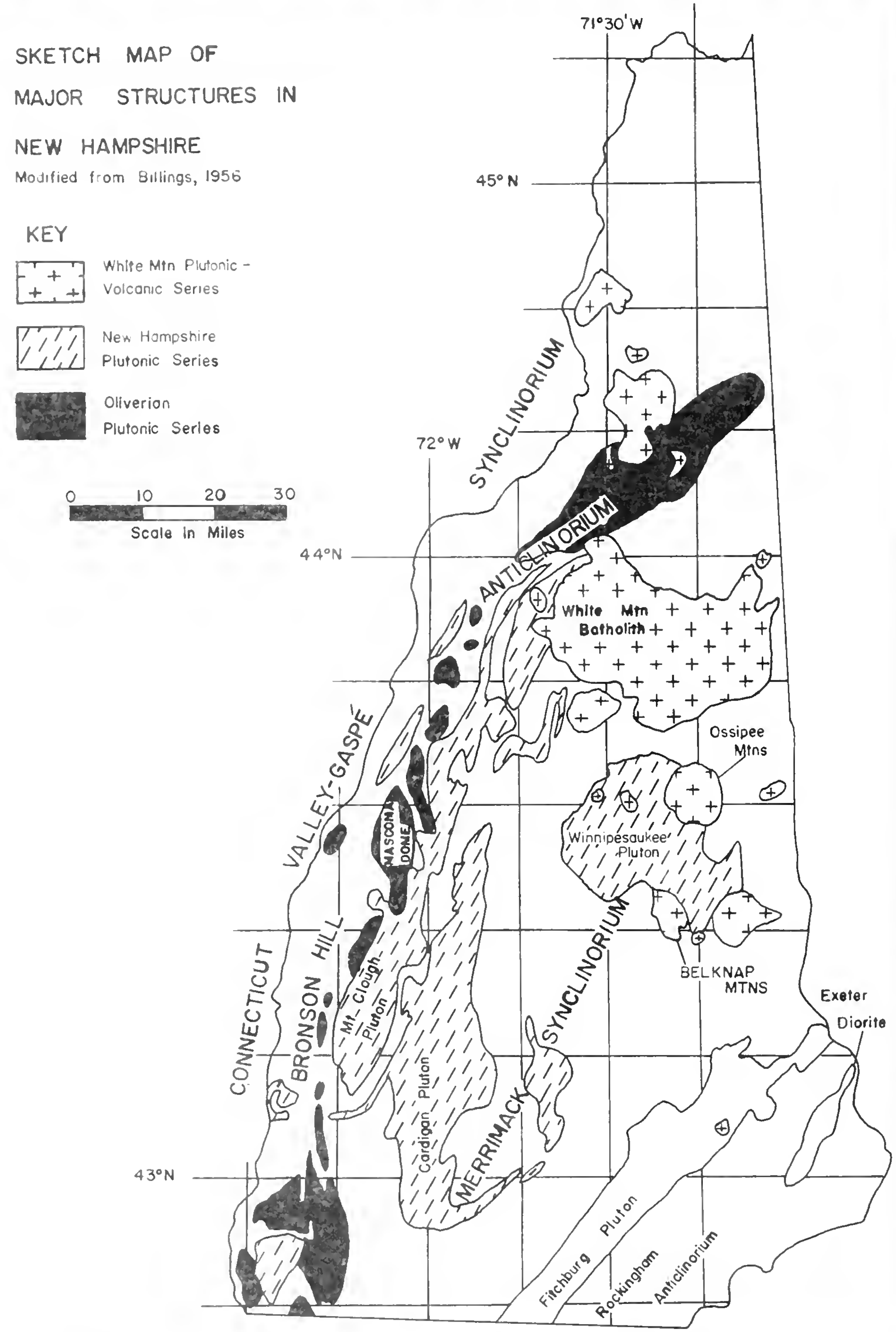
SKETCH MAP OF
MAJOR STRUCTURES IN
NEW HAMPSHIRE
Modified from Billings, 1956
KEY
White Mtn Plutonic - Volcanic Series
New Hampshire Plutonic Series
Oliverian Plutonic Series
0 10 20 30
Scale in Miles
71°30'W
45° N
72° W
44°N
43°N
SYNCLINORIUM
ANTICLINORIUM
White Mtn Batholith
Ossipee Mtns
VALLEY-GASPÉ
MASCOMA DOME
Winnipesaukee Pluton
BELKNAP MTNS
CONNECTICUT
BRONSON HILL
Mt. Clough Pluton
SYNCLINORIUM
MERRIMACK
Cardigan Pluton
Exeter Diorite
Fitchburg Pluton
Rockingham Anticlinorium

Figure I.

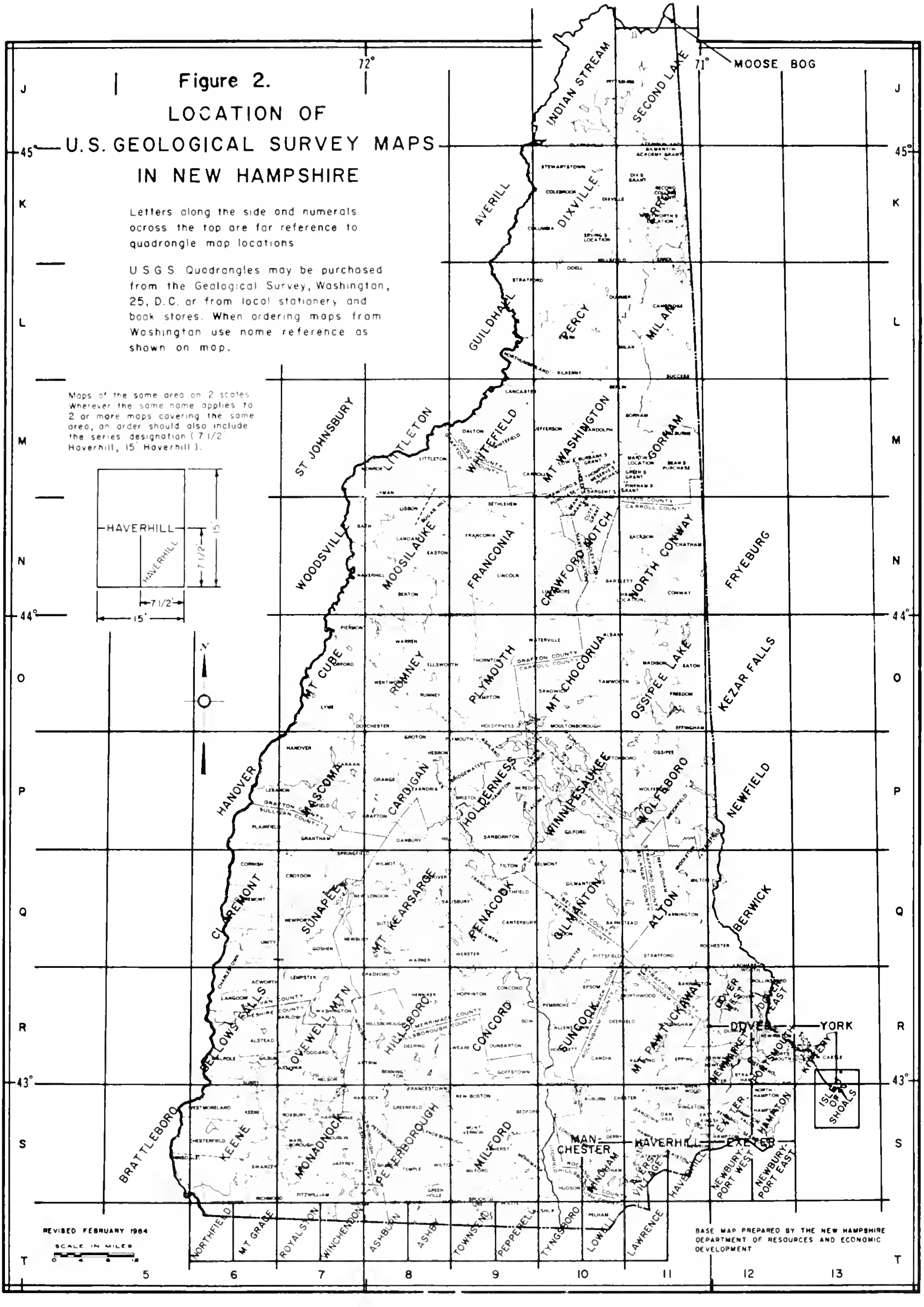

Figure 2.
LOCATION OF
U.S. GEOLOGICAL SURVEY MAPS
IN NEW HAMPSHIRE

Letters along the side and numerals across the top are for reference to quadrangle map locations

U.S.G.S. Quadrangles may be purchased from the Geological Survey, Washington, 25, D.C. or from local stationery and book stores. When ordering maps from Washington use name reference as shown on map.

Maps of the same area on 2 scales. Wherever the same name applies to 2 or more maps covering the same area, an order should also include the series designation (7 1/2' Haverhill, 15' Haverhill).

Since its first recognition by Billings in 1928 in the North Conway Quadrangle, the White Mountain Plutonic-Volcanic Series has served as a focus for scores of studies of its structure, petrology, radioactivity and radiometric age. Only recently (1971) papers by Foland, Quinn and Giletti, and by Armstrong and Stump reported a spread in radiometric ages for the White Mountain series ranging from 218 to 100 m.y. To geologists indoctrinated with the classical concept of a petrographic province and with the idea that rocks which are petrographically identical are also coeval, there are some rather staggering implications in these radiometric dates, suggesting that the continued study of the White Mountain Plutonic-Volcanic Series is eminently worthwhile. Results of recent field studies in the Ossipee Mountains ring dike complex and adjacent areas will be displayed by Page in Trip A-5 and by Wilson on Trip A-8. The Belknap Range is also being restudied by Bothner and Gaudette (Trip B-3) whose excursion features some elegant new exposures along the west shore of Lake Winnipesaukee.

The nappe reinterpretation of the structure along the Bronson Hill anticline, first unveiled by J. B. Thompson at the 1954 NEIGC Conference, has been expanded and elaborated upon by Thompson, Robinson, Clifford and Trask in Studies of Appalachian Geology, Northern and Maritime. Their map stops at the southern boundary of the Mt. Cube Quadrangle where Rumble (Trip A-6) takes up the question of the northward extension of the Skitchewaug nappe. Several intriguing questions arise in the Mount Cube area. If the nappes trace northward through this quadrangle, where do they finally end? Why does the thick (5000 feet ?) Albee Formation trace southward for more than 100 miles into the northern part of the Mt. Cube Quadrangle, and terminate there? Is there any reason for retaining Hadley's (1942) Orfordville Formation if the structure is reinterperted on the nappe basis?

The Mascoma Dome, tracing from the Mascoma Quadrangle into the southern portion of the Mt. Cube Quadrangle is the type area used by Naylor (Trip A-4) to expound his interpretation of the Oliverian domes as classic mantled gneiss domes, fitting the pattern visualized by Eskola. Central to Naylor's argument, in addition to radiometric dates which show a Highlanderoft (Ordovician age) for the supposedly Lower Devonian Oliverian

Magma Series, is the reinterpretation of much of the core material of the Mascoma Dome as meta-rhyolite rather than intrusive granite, and the rejection of Chapman's (1939) conclusion that the Clough Quartzite (Silurian) has been granitized by the Mascoma Dome.

East of the Bronson Hill anticline are the stocks, sheets, and batholiths of the Middle to Upper(?) Devonian New Hampshire Plutonic Series which cut through the major structure of the Merrimack Synclinorium. On its southeastern side the synclinorium abuts against a 5 to 10 mile wide belt of plutonic and metamorphic rocks grouped collectively into the Fitchburg Pluton. Four excursions, A-2, A-3, B-2 and B-6 deal with the somewhat murky geology of the synclinorium.

Billings' Geologic Map of New Hampshire (1955) places all of the metamorphic rocks of the synclinorium into the Lower Devonian Littleton Formation, but the reinterpretation of the geology of the Bronson Hill anticline by Thompson _et al_ converts some of the Littleton into the Partridge Formation, involves the Mt. Clough pluton of Bethlehem Gneiss in the nappe structures, and raises additional problems, some of which are encountered on these excursions.

Along the Bronson Hill anticline a self-consistent nappe interpretation is possible if quartzites and quartz conglomerates formerly mapped as Orfordville, Clough, and Littleton are considered to be Clough, and if dark rusty-weathering, sulfidic, graphitic, black schists are mapped as the Partridge Formation. This raises the c.b.s. (cruddy black schist) problem -- i.e. are all rusty sulfidic, graphitic black schists in the Merrimack synclinorium Partridge? If not, how do we tell Partridge black schists from those of other formations? Related to this is the question of whether calcareous metasedimentary rocks (Trips A-2, A-3, B-6) have a single assignable stratigraphic age, or whether they represent facies variants of several different formations and ages.

Vernon (Trip B-6) in the Concord Quadrangle and Greene (Trip A-2) in the Peterborough Quadrangle map their metasedimentary units as members of the Littleton Formation. Greene (Trip A-2) fixes the axis of the Merrimack synclinorium in a northeasterly trending line passing through the northwestern part of the Peterborough Quadrangle, and Vernon's mapping in the Concord

Quadrangle is consistent with the projection of this axis through the northwestern part of the Concord Quadrangle. From here it would extend northeasterly, passing through the Ossipee Lake Quadrangle (Wilson, Trip A-8), and meeting the Maine state line at a latitude of approximately 44° 00' N.

In contrast to the interpretation just cited, the Generalized Geologic Map of the Northern Appalachian Region by Zen, White, Hadley and Thompson projects an antiform of inverted(?) Ordovician rocks (Partridge?) from southwestern New Hampshire toward Concord, with its axis lying a few miles east of Green's projected trace of the Merrimack synclinorium. To say, then, that there is some current uncertainty concerning the structure of the synclinorium is to understate the problem. The structural complexity within the synclinorium itself is demonstrated by Englund in the Holderness Quadrangle (Trip B-2), where at least 2 and probably 3 cycles of deformation may be deciphered within the Littleton (?) formation. Here, as elsewhere, the black schist problem is both the hope and despair of a final resolution of structure and stratigraphy.

The largest body of the Kinsman Quartz Monzonite in New Hampshire is the Cardigan pluton, which is 60 miles long and up to 12 miles wide. Its origin has been controversial and this question, its possible relation to nappe structures, and its 3-dimensional shape (a surprisingly thin sheet) are the subject of Trip A-3 by Lyons and Clark.

The Fitchburg Pluton, a complex of metamorphic and igneous rocks up to 10 miles wide, extends from near the Maine border through the city of Manchester and into Massachusetts. Although two excursions were originally planned to examine the pluton in the Manchester and Suncook Quadrangles, neither trip materialized. Those on Trip A-2, however, are alerted to look closely at the Massabesic Gneiss, an extraordinarily coarse-grained sillimanite-potash feldspar gneiss on which R. P. Naylor (oral communication) has determined a tentative Rb-Sr Precambrian age. If the date is confirmed, it adds another complication to a belt of rocks generally considered to be in normal stratigraphic succession on the eastern limb of the Merrimack synclinorium, or on the western limb of the Rockingham anticlinorium. A confirmed Precambrian date on the Massabesic Gneiss would, of course,

suggest the possibility that it represents some of the root zone for nappes which may extend from here to western New Hampshire.

The Rockingham anticlinorium, in the Haverhill Quadrangle, is cut by a variety of intrusives related to the Hillsboro Plutonic Series which progress from granite (the oldest) to norite (the youngest). On Trip A-7 Sundeen will demonstrate the field criteria used to determine the igneous sequence, and will set forth his ideas on deep crustal melting as a mechanism for explaining the abnormal intrusive sequence.

At the boundary between southeastern New Hampshire and northeastern Massachusetts is the Newburyport pluton whose age has been variously assigned from the Precambrian to the Devonian, and whose relation to other plutonic groups in northeastern Massachusetts such as the Salem Gabbro-Diorite and the Dedham Granodiorite has long been controversial. In Trip B-5, Shride details the evidence which allows him (1) to delineate three variants within the Newburyport pluton, (2) to demonstrate that a major regional fault, the Scotland Road Fault, separates the Newburyport pluton from another group of diorites and quartz monzonites to the south, and (3) to show that these latter rocks are unrelated to either the Newburyport pluton or the Salem Gabbro-Diorite.

Finally, no series of geological field excursions should end without a bow to the oceans from whence, we are now told, all good geological things come. Anderson and Tischler (Trip B-1) will show to those lucky enough to clamber aboard ship (a nautical first for the NEIGC) the research they have been doing during the past two years in the tidal estuary of Great Bay.

GLACIAL FEATURES OF WINNIPESAUKEE - WOLFEBORO AREA

Richard P. Goldthwait
The Ohio State University
Columbus, Ohio

Introduction

The geological problems to be studied on this excursion are glacial problems. We hope to discern from detailed surficial mapping, and reasoning from deposits we see in the Lakes Region:

(1) Evidence that more than one passage of glacial ice moved over here (STOP 2).

(2) How did this ice flow and erode? Depth and direction. (STOPS 4, 5 7).

(3) Just how did it disappear? Ice depth, slope, sequence of basins uncovered (mostly STOPS 1, 3, 6, 8).

(4) Some interesting and often-neglected postglacial landforms: fans, ice-shove boulder ramparts seen along the way.

Note that you will need to listen and follow the log en route between stops, as many things are seen out the bus window. We will slow down while passing.

All of the source material is summarized and fully illustrated in "Surficial Geology of the Wolfeboro-Winnipesaukee Area, New Hampshire" by Richard P. Goldthwait (1968), published and available ($2 a copy) from the Department of Resources and Economic Development, State Office Building, Concord, N.H., 03301, complete with three colored maps. You can hardly get all the "lowdown" without it, so we will try to have copies for sale. Numbered figures below are in this "Surficial Geology of the Wolfeboro-Winnipesaukee Area" only, and we follow its two colored quadrangle maps. Bedrock summaries are older: "The Geology of Winnipesaukee Quadrangle, New Hampshire" (1941) and "The Geology of the Wolfeboro Quadrangle..." (1953) both by Alonzo Quinn, and available from the same source.

ROAD LOG FOR TRIP A-1

Mileage

0 miles Leave CONCORD north on I-93 for 17 miles to Tilton, noting as you go:

- 2 mi. Bridges across the shifting Merrimack River require revetment because earlier uninhibited flood-cutting rates were up to 6' per year.
- 4 mi. E. Concord san plain; an outwash delta into glacial Lake Merrimack.
- 13 mi. Thin drift over wooded hills; drilled wells average 13' of drift on hills.

17 miles Turn righ on US-3 for 9 miles to outskirts of Laconia, noting at:

- 1 mi. Thick sandy drift filling the valleys; washed off stagnant last ice.
- 4 mi. Lakes gouged by ice in preglacial valley (Fig. 1).

26 miles Turn right on Laconia By-Pass for 2 miles to NH-106 exit and turn there to the pits just to the north. Here we follow the Winnipesaukee Surficial Geologic Map (this new road is not on it).

- 1/2 mi. Glacial hillside channels sloping west, on our right (S).
- 1 mi. Same on left (N).

28 miles STOP 1 in pit of kame-delta complexes fringing Laconia. Items for discussion:

(1) The ice melted primarily downward, as shown by marginal stream gradients and increasing concentrations of stratified drift lower down, resulting in blockage of waters here. Evidence for different standing water levels, and necessity of ice contact.

(2) This area and the Brookfield-Wakefield Valleys (eastern portion of the Wolfeboro Quadrangle) were the first of six basins evacuated by glacial ice in east-central New Hampshire, so the ragged ice edge did retreat roughly northward. Evidence of meltwater channel directions and ice contact trapped deposits. (Table 2)

(3) History of the arguments in the 1930's about deglaciation.

29 Miles Return to Laconia By-Pass and go north 4 1/2 miles to Route NH-11, noting:

1 mi. Dry glacial channels on the hillsides beyond "City Line".

1 1/2 mi. Kame sand pits right and left; water down NH-11A from Gilford col channel to the north-east.

2 mi. Host of dry former channels (24 in all) at various levels diagonally down south hillslope (partly under ice?).

3 1/2 mi. Channel to the west, high across the north face of the hill (just before an underpass).

4 mi. Chute on right, cut under the ice.

34 miles Swing around right in the cloverleaf under ourselves and head south.

1/2 mi. on NH-11 to Lakes Shopping Plaza where we park.

35 miles STOP 2 on slope behind stores to see till sequence. Items for discussion:

(1) What are the two or three tills? Upper till here is loose, sandy, yellow-gray, with a podzol soil top, and shows eight ablation till (wasting ice) characteristics. Lower till here is compact, more clayey and shows eight basal till characteristics. But one characteristic is wrong here; the older till is weathered yellow, and has deep joint staining. Time of its deposition?

(2) History of two till arguments: 1968 trips. A possible solution to two views here.

(3) Lacustrine varved beds beneath and near Melvin Village; an earlier Lake Winnipesaukee? Date of this advance?

35 miles Return north on NH-11 1/2 mile to 11B and turn right (S) on it 2 mi. to 11A, noting enroute:

1 mi. Airport on left is on low sand fill or wash, characteristic of low areas without ice contact or thick terrace deposits. An earlier sandy esker lies along the north side.

2 1/2 mi. Gentle fan slope washed in late glacial times from sandy gravel deposits up-valley; controlled by topography here.

40 miles POSSIBLE STOP 3 in Gilford gravel kame pits right (W), showing for discussion:

(1) Coarser kame material high above valleys. indicating early fast moving water, (under ice?).

(2) Ice blockage of northward-running valleys yielded coarser ice-contact deposits, again showing retreat roughly northward.

(3) But material came from the north via ice and ice water streams (Table 1, upper part).

40 miles Turn left (E) on NH-11A for 2 1/2 miles. Note now at:

1 mi. Fine views left overbroadest part of Lake Winnipesaukee. Does the 196' depth of closure (bedrock threshold at Wiers) mean 196' of ice excavation in the old valleys (Fig. 1)?

42 miles Turn right (S) into Belknap County Recreation Area for

1 1/2 mile to picnic grounds. Note:

1 mi. Just beyond fence, an old "rotten stone pit" in syenite under thin till, and believed by many to be a residual spot of preglacial weathering.

44 miles Go out (E) to NH-11A and southeast 6 mi. to join NH-11.

Note at:

1 1/2 mi. This is another north-facing valley, full of rough kames, to the right (as at STOP 3).

3 1/2 mi. High early melt waters spilled over eastward where we pause (Fig. 8, detailed map) making a deep channel, hanging at this end, and showing higher ice to the north. Another channel lies uphill, right (S) of us.

5 1/2 mi. Kames (pits L) lower on slopes below channels signify lower ice surface level here (?).

50 miles Turn right (S) on NH-11 for 3 1/2 miles to roadside parking area.

54 miles VIEW STOP 4 overlooking Alton Bay. Discussion:

(1) Narrow "headwaters" of preglacial valley, right (S) as on Fig. 1, due to resistance of Belknap ring dike.

(2) Did ice erode more than 65' of rock - the depth of water below you? Drift thickness suggests a minimum average everywhere of 26 feet.

(3) Ice deepened the 6 major and 7 minor arms of Lake Winnipesaukee to straits elongated S41°E. Here the bay and striae go SSE. The ice turned.

(4) Opposite is ridge after ridge (in Wolfeboro Quad.) of rock drumlins. The 99 in all average S36E (Fig. 4).

(5) Below you left (through field glasses) are some of the many small islands bearing boulder tails built by shifting lake ice in March-April each year. (Fig. 12, 13, 14, 15)

54 miles Proceed south on NH-11 to Alton Bay 8 miles, noting in:

1 mi. Big boulders moved only a fraction of a mile, mostly, but common in ablation moraine near certain granites.

2 mi. More ice-contact kames with pebbles moved southward; late glacial waters seeking the Alton threshold. Farmington Valley (S) melted out first.

62 miles Turn left 4 miles on NH-28A up the east side of Alton Bay OR continue south 1 mi. to Alton to join route 28 north in either case. Note: Alton threshold on your right carried glacial drainage just above lake level but there is no overflow today.

Enter Wolfeboro Surficial Map.

66 miles Turn left again (N) on NH-28 for 1 (or 5 mi.) to "View Parking".

67 miles QUICK STOP 5 at bedrock overlook of Roberts Cove. This is the northwest side of the hill west of Gilman Pond (new road not on map).

(1) Glacial grooves here trend about S20E (see Fig. 3) and the rock drumlins S30E.

(2) Till fabrics nearby agree generally but the pebbles in very bottom till, next to any bedrock sloping sidewise or obliquely, seem to be twisted downslope by 10-30° (Drake). Why?

67 miles Continue northeast 8 1/2 miles on NH-28 through South Wolfeboro (L turn) and Wolfeboro (R turn). Note at:

4 mi. At South Wolfeboro the NW-SE elongation of Rust Pond like 16 other ponds here. Three fourths of all lakes are S50°E ± 25° mostly in weak Winnipesaukee Quartz Diorite.

4 1/2 mi. Where we pause to note the ice-shove boulder spit, if visible, 200' to the right.

76 miles POSSIBLE STOP 6 at Allen-A sand pit. Discussion:

(1) This is a delta with foresets S to E, lobate, and a broad flat top. But it is dimpled with kettles so ice was near.

(2) There is no other matching delta level or shore, so what held L. Wentworth 70' higher? Wasting ice, and local ponding.

(3) This was third but not last of the 6 basins to deglaciate, for waters came east via Hersey Cemetary channel to build this delta, and it went out southeast (channels either side of Cook Pond).

76 miles Continue over 1 1/2 miles north to "College Road" Corner beyond NH-109 junction.

78 miles STOP 7 on the old (1790) Gov. Wentworth road from East Wolfeboro to Dartmouth College. Discussion:

(1) The Red Hill Boulder Train (Fig. 7A) counted on the stone walls. Methods.

(2) Lateral (compact) and longitudinal (elongate) exponential dispersal.

(3) Why does the stoss-slope of a hill concentrate erratics in some places?

(4) Total loss to Red Hill was 45' depth, more or less. We can replace all the syenite rocks and minerals to get this.

(5) Peculiarly balanced "rocking stones" on bedrock ledges. One in the woods 300' east of here.

78 miles Continue northeast on NH-28 for 6 miles to NH-171 crossing. Noting as you go:

1 1/2 mi. Sandy kame deltas (pits in foresets), 100' higher than at STOP 6. Channel (Fig. 9) is higher than 900' in elevation and one mile right (NE).

2 1/2 mi. Gravel kames at still higher levels (800-900'). This is the usual sequence consisting mostly of local material (Table 1 middle).

3 1/2 mi. Pond and swamp dammed repeatedly by beaver, amongst ice-contact deposits. Enter the Ossipee Mountain Boulder train (fig. 7B) here.

84 miles Turn right (E) for 2 miles through Ossipee on NH-171.

1/2 mi. Ossipee is on a neat pitted kame terrace formed at 680' after the esker branch (N) flowed uphill to 720'.

1 1/2 mi. Approach branch esker of Pine River esker, left (N). You are in the heart of a huge esker-kame ice-contact complex of deposits (see colored Wolfeboro map). This and similar tree-like branches in the eskers of the Ossipee Lake

quadrangle to the north are evidenced that drainage did flow south.

86 miles Turn right (SE) on NH-16 for 2 miles approaching Pine River esker (Fig. 10, you are on it). At Pine River bridge and spur railroad turn left into pit.

88 miles <u>LAST STOP 8</u> in Pine River Esker at bend of Route 16. Discussion:

(1) Where was the ice surface when this formed? Hillside channels (W) and chute deposits along Youngs Brook and high kames seem to suggest 300' ice thickness over your head, and 500' ice thickness further north near Route 25.

(2) Imbrication, cross bedding, tributary Y pattern, and above all, pebble counts (Table 1) demonstrate that water flowed south - UPHILL.

(3) The same structures and continuity of internal beds say that it was all deposited at once (not seriatim as some would have, or as some eskers are).

(4) It is very coarse (3' boulders common) so energies were great and this much material could be gained only from lower dirty ice or basal till erosion.

(5) Adjacent satellite ridges are lower, finer, with swampy fosses as usual. Although the main stem of the drainage system divided in places (Round, Snake, White, and Lost Ponds) these ponds appear to be later (some kames superposed) and formed when the water flowed more slowly (sandy deposits).

(6) Open flat-top, but kettled, kame terraces could not form until ice was thin, and large lateral depressions were open to the sky. These top at 530' (E) to 580' (W), so seem to lead to a lower threshold east to Providence Lake - a later event (Table 2).

(7) Lower sand plains and fill were let down, exposed, or washed out last. Thus the typical sequence for all deglaciated valleys.

(8) This valley and perhaps ice just south of Ossipee Mountains were the last to melt out (Table 2).

88 miles Return to NH-16 and return right (N) 2 miles on NH-171, left (SW) 44 miles on NH-28, and right (W) 10 miles into Concord on NH-9; 58 miles in all, <u>OR</u> turn left (S) on NH-16 for 37 mi. to Rochester, and right (W) on NH-9/US-202 for 34 miles to Concord, 71 in all.

TRIP A-2

PETERBOROUGH QUADRANGLE _/

Robert C. Greene
U.S. Geological Survey
Menlo Park, Calif.

General Discussion

This trip will provide a cross section of the southeast limb of the Merrimack synclinorium by means of a northerly and, finally, westerly traverse across the Peterborough quadrangle (figure 1). The four members of the Littleton Formation recognized in this area (Greene, 1970) will be observed, along with the major types of plutonic rocks.

At New Hampshire's south boundary, that part of the Merrimack synclinorium occupied by the Littleton Formation is only about 24 miles wide. The beds strike predominantly north-northeast. Southeast of a line through Crotched Mountain and Mount Monadnock, dips are predominantly northwest; northwest of this line they are mostly southeast; thus the synclinorial axis is defined.

In the Peterborough quadrangle, analysis of bedding strike and dip and of fold axes and axial planes shows that the southeast limb of the Merrimack synclinorium is a relatively simple homoclinal sequence in which beds get younger to the northwest. It is complicated, however, by numerous minor folds. Fold axes mostly trend northeast and plunges are gentle northeast, horizontal, or, less commonly, gentle southwest. Axial planes dip vertically to 60° northwest.

As there are no major folds smaller than the Merrimack synclinorium, the sequence of units across the Peterborough quadrangle is nonrepetitive.

_/ Publication authorized by the Director, U.S. Geological Survey

It is as follows:

Littleton Formation:

Crotched Mountain Member_/	5,320 feet
Francestown Member_/	80 feet
Peterborough Member_/	13,055 feet
Souhegan Member_/	6,460 feet

These thickness figures were derived from a calculation utilizing structure diagrams (Greene, 1970, p. 36-40). The units will be examined from the base up, starting in the Massabesic Gneiss of Sriramadas (1966) (Stop 1) a mixed rock derived in part from the Souhegan Member. The Souhegan Member will be seen at Stop 2; Peterborough Member at Stops 5, 6, and 7; the Francestown Member at Stop 8; and the Crotched Mountain Member at Stop 9.

Schist and granulite consisting predominantly of quartz, plagioclase, muscovite, and biotite with minor garnet and sillimanite are the principal rocks of the Souhegan, Peterborough, and Crotched Mountain Members. All are metamorphosed to sillimanite grade.

Major intrusive rocks are the Spaulding Quartz Diorite (Stop 3), Kinsman Quartz Monzonite (Stop 10), and binary quartz monzonite (Stop 3). All belong to the New Hampshire Plutonic Series. Rocks in each unit range through several steps in the sequence quartz diorite, granodiorite, quartz monzonite, granite. Quartz diorite generally contains plagioclase, quartz, and biotite, whereas the others contain plagioclase, microcline, quartz, muscovite, and biotite.

_/ Of Greene (1970)

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It is as follows:

Littleton Formation:

Crotched Mountain Member_/	5,320 feet
Francestown Member_/	80 feet
Peterborough Member_/	13,055 feet
Souhegan Member_/	6,460 feet

These thickness figures were derived from a calculation utilizing structure diagrams (Greene, 1970, p. 36-40). The units will be examined from the base up, starting in the Massabesic Gneiss of Sriramadas (1966) (Stop 1) a mixed rock derived in part from the Souhegan Member. The Souhegan Member will be seen at Stop 2; Peterborough Member at Stops 5, 6, and 7; the Francestown Member at Stop 8; and the Crotched Mountain Member at Stop 9.

Schist and granulite consisting predominantly of quartz, plagioclase, muscovite, and biotite with minor garnet and sillimanite are the principal rocks of the Souhegan, Peterborough, and Crotched Mountain Members. All are metamorphosed to sillimanite grade.

Major intrusive rocks are the Spaulding Quartz Diorite (Stop 3), Kinsman Quartz Monzonite (Stop 10), and binary quartz monzonite (Stop 3). All belong to the New Hampshire Plutonic Series. Rocks in each unit range through several steps in the sequence quartz diorite, granodiorite, quartz monzonite, granite. Quartz diorite generally contains plagioclase, quartz, and biotite, whereas the others contain plagioclase, microcline, quartz, muscovite, and biotite.

_/ Of Greene (1970)

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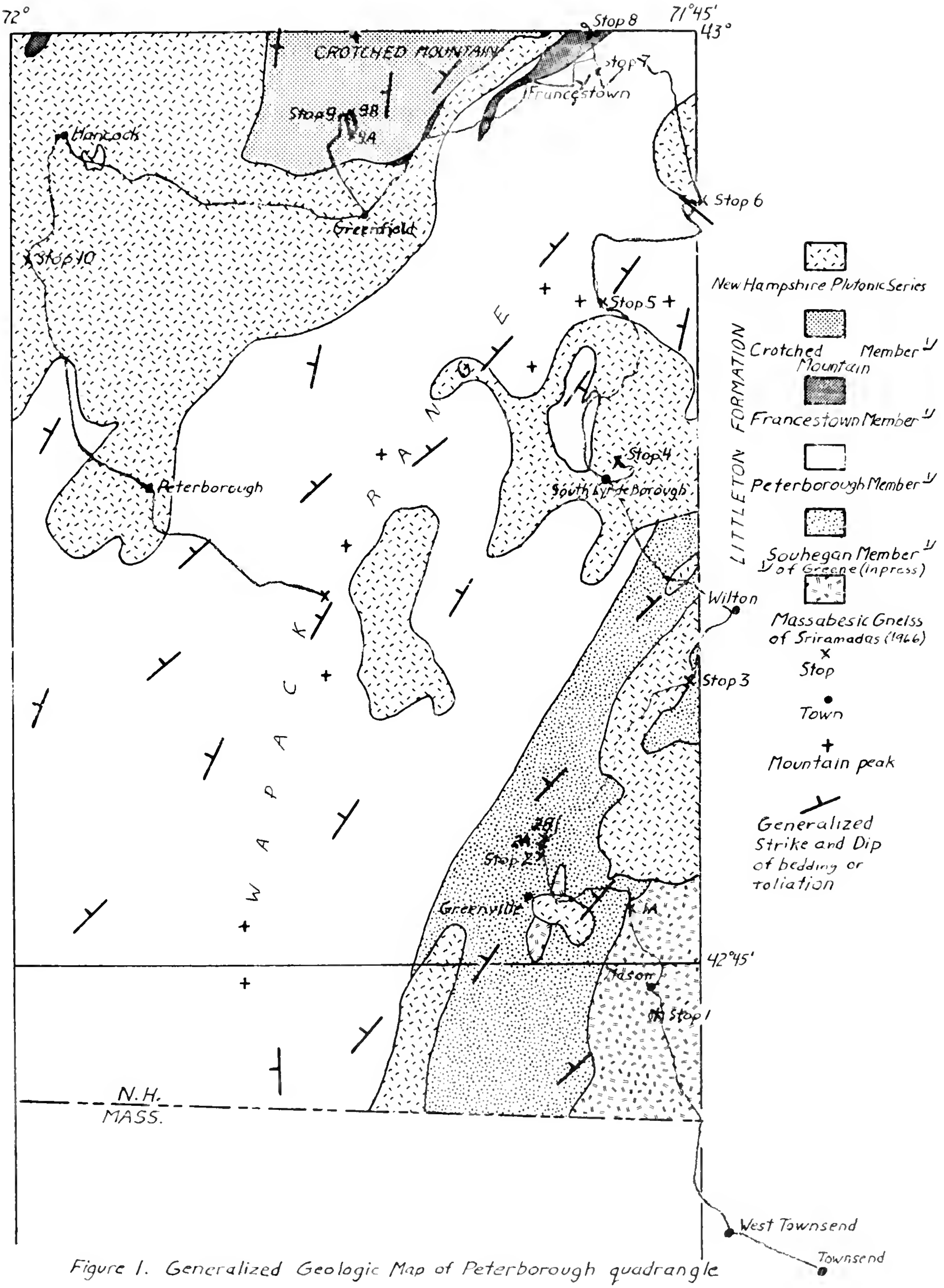

Figure 1. Generalized Geologic Map of Peterborough quadrangle

ROAD LOG FOR TRIP A-2

From Concord take Interstate 93 south for 16 miles to Manchester. Then follow Route 101 for 11 miles southwesterly to Milford, where Route 13 is picked up and followed southerly for 14 miles to Townsend, Mass. Road log begins here.

Mileage

0.0 Junction routes 119 and 13, Townsend, Mass. Go west on route 119.

1.9 West Townsend. Turn right at sign for Greenville, N. H., and New Ipswich, N. H., no route number.

3.2 Bear right, sign for Mason, N. H.

4.3 New Hampshire state line, begin route 123.

6.7 Turn left onto Cascade Road.

6.8 STOP 1 Massabesic Gneiss in stream cascade to left of road. Massabesic Gneiss was named after Massabesic Lake in the Manchester quadrangle (Sriramadas, 1966), and is probably continuous from the type locality to the southeast corner of the Peterborough quadrangle. Here it consists of granodiorite and quartz monzonite containing plagioclase, microcline, quartz, biotite, and minor muscovite. Well foliated, layered, and porphroblastic at this locality. Please do not hammer on this outcrop.

Turn around and return to route 123.

7.0 Turn left (north) on route 123.

7.5 Mason. Bear right onto Wilton Road. Scattered outcrops of Massabesic Gneiss to Stop 1A.

9.2 STOP 1A Massabesic Gneiss in cliff, to right of and below road. Contains sills of granodiorite and partings of schist with the character of the Souhegan Member of the Littleton Formation.

Continue north on Wilton Road.

10.4 Stop sign. Bear left.

11.3 Stop sign. Turn right onto Greenville Bypass, route 31.

11.6 Begin series of roadcuts exposing micaceous schist and rare quartzose granulite of Littleton Formation, Souhegan Member, intruded by granodiorite, pegmatite, and aplite. Type locality of the Souhegan Member.

Milcage

12.0 STOP 2 Schist of the Souhegan Member, evenly foliated and somewhat banded. Characteristic sheen from parallel orientation of micas, patchy concentrations of biotite or muscovite common. Permeated with pods and stringers of plagioclase and quartz. Prominent lineation.

Continue north on route 31.

12.6 STOP 2A Schist of Souhegan Member, intruded with granodiorite and pegmatite. Pegmatite consists of large crystals or masses of perthitic microcline with a characteristic ivory color, and smaller interstitial quartz, plagioclase, microcline, and muscovite.

13.0 STOP 2B Pegmatite and aplite in typical layered arrangement.

13.3 Cross Souhegan River, end series of outcrops.

14.4 Gravel pit on left, well stratified cobble gravel. Melt-water deposits, probably filled a lake formed by ice-damming of the Souhegan River downstream. As much as 200 feet thick in this vicinity.

15.2 Gravel pit on left, crossbedded sand and gravel.

16.2 Junction route 101. Bear right (east) on routes 101 and 31 towards Wilton.

16.8 STOP 3 Roadcuts both sides of road. On left, Spaulding Quartz Diorite with prominent foliation, crosscut by dikes of granodiorite and pegmatite. A small, elongate body; crops out only in this cut. On right, binary quartz monzonite, pegmatite, and aplite, with partings of schist, part of Pratt Pond pluton, a body of granodiorite at least 5 miles long, formerly quarried at several localities to the south and east as "Milford granite".

Continue east on routes 101 and 31 towards Wilton.

17.4 Cross Souhegan River. Outcrop of schist of Souhegan Member under old bridge to right.

18.2 Blinker light. Turn left, following route 31 into Wilton.

18.6 Turn left, follow route 31 (northeast) towards South Lyndeborough.

19.0 Begin series of roadcuts; schist of Souhegan Member with minor granodiorite.

19.5 Diabase dike on right, one of several postmetamorphic dikes in the southeast part of the Peterborough quadrangle. Probably Triassic in age.

Mileage

19.7 Roadcuts from here on are foliate Spaulding Quartz Diorite and pegmatite. A small body similar to the one observed at stop 3.

19.9 Railroad crossing, End series of outcrops.

20.0 Cross Stony Brook. Bear right, continue northeast on route 31.

22.2 South Lyndeborough, railroad crossing. Turn sharp right.

22.3 Keep left.

22.5 Keep left.

22.8 Turn left onto dirt road.

23.1 STOP 4. Quarry in white quartz rock of silicified zone. Elongate bodies of quartz rock are aligned in two bands across east-central part of Peterborough quadrangle. The bodies are probably connected by faults, which by analogy with silicified zones in the Keene quadrangle (Moore, 1949), are probably Triassic normal faults. Quartz rock quarried here is crushed and used for decorative purposes, such as exposed aggregate.

Turn around and return to South Lyndeborough.

23.9 South Lyndeborough, same point as 22.2 miles. Bear right, continue north on route 31.

24.4 Turn right at sign for Lyndeborough Center.

25.6 Junctions, keep right.
25.7
25.9
26.2 Pond on right.

26.9 Turn left, paved road.

27.2 Badger Pond on right.

27.5 Junction. Go Straight ahead.

27.6 View of Wapack Range. Seen are, south to north, Temple, Pack Monadnock, North Pack Monadnock, Winn, and Lyndeborough Mountains.

Mileage

28.7 STOP 5. Top of rise, large mailbox on right, house beyond. Roadcut on left, several outcrops near house; please do not hammer on these. Lane to right, later path leads to open blueberry pastures with many glacially smoothed outcrops of schist of the Littleton Formation, Peterborough Member, also granodiorite and pegmatite. Schist is of both granulitic and micaceous types, commonly with garnet and (or) sillimanite. Excellent bedding in several places, grading not seen. This is one of the summits of Lyndeborough Mountain. Here the Wapack Range bends sharply from northeast to east to southeast trending. This is not reflected in the strike, however, which remains dominantly northeast.

Continue in same direction (north) after stop.

29.9 Pavement ends. The north slope of the Wapack Range is here, as elsewhere, largely covered with drift. From here to 31.0 the road crosses several drumlins whose long axes are all close to N. 30° W.

30.0 Junction, turn right.

31.3 Junction, bear left.

31.7 Gravel pit on left, crossbedded sand and gravel (outwash).

32.0 T-Junction, paved road. Turn left.

32.2 Junction. Turn left (northwest) toward Francestown.

32.7 Turn right onto sand road, sign for Clark Hill Farm.

33.1 STOP 6. Bridge over Piscataquog River. Granodiorite upstream; severely retrograded schist of Littleton Formation, Peterborough Member, downstream. Dark-green schists consist mostly of muscovite, partially to wholly converted to chlorite. Unusual northwest strike with southwest dip.

Bear left after crossing bridge and continue north.

33.4 Cross paved road, continue straight ahead.

34.9 Outcrop of quartz=plagioclase granulite, part of a small lentil of volcanic rocks separately mapped in this area.

35.2 Haunted Lake on the left. From here to 36.4, road goes between several prominent drumlins. Axes are all close to N. 20° W.

35.6 Junction, keep left.

36.8 T-Junction, paved road, turn left (west).

37.3 Turn right, paved road, sign for soapstone quarry.

Mileage

37.7 STOP 7 Soapstone quarry. Hitchcock (1878) reports soapstone was discovered here in 1794 and first worked in 1802. The material was used for stoves, sinks, and wash-boards, and became quite famous for its high quality. The soapstone consists of talc, phogopite, tremolite-actinolite, and chlorite. Wallrocks are mostly normal schists of the Littleton Formation, Peterborough Member, but a few transitional rocks are also found. Thick brush and poison ivy; use care. Most accessible for collecting are blocks of soapstone on the north side of the quarry.
Straight ahead after stop.

38.2 STOP 8 Roadcut and natural exposures of rusty granulite of the Littleton Formation, Francestown Member. Granulites consist mostly of quartz and plagioclase; some also contain muscovite, others actinolite and clinozoisite. Weathering of pyrite gives an extremely rusty surface and, commonly, a sulfurous odor. This unit was mapped as the Rusty Quartzite Member of the Littleton Formation in the Monadnock quadrangle (Fowler-Billings, 1949).

Go straight after stop. Roadcut exposures continue, also natural exposures in cuestalike ridges to left.

38.5 End exposures, turn around.

39.2 Turn right onto gravel road.

40.1 T-Junction, paved road, turn right.

41.0 Francestown. Bear left, follow route 136 towards Greenfield.

44.6 Swamp on right. Crotched Mountain Center on bluff above.

45.4 Greenfield. Turn right onto route 131, then turn right again, continuing on route 131.

46.1 Outcrops of Kinsman Quartz Monzonite to right. This is the easterly trending "hook" at the south end of the Cardigan pluton.

46.2 Turn right, sign for Crotched Mountain Center.

46.7 Nashua Fresh Air Camp on right. Exposures of inter-fingering schist and quartz monzonite in contact area.

46.8 Rusty granulite in roadcut on right.

47.7 STOP 9 Turn right toward Crotched Mountain Center and stop. Outcrops of schist of Littleton Formation, Crotched Mountain Member, across road. Some of the schist contains the large sillimanite porphyroblasts that distinguish the Crotched Mountain Member.

Go straight after stop.

48.1 STOP 9A Driveway to main buildings of center. Outcrops on left are well-bedded schist and granulite of Crotched Mountain Member with sillimanite and garnet porphyroblasts. View southwest to Mount Monadnock, south to Pack and North Pack Monadnock Mountains, southeast to Winn and Rose Mountains and Joe English Hill and east to Uncanoonoc Mountains.

Bear left continuing on main loop road.

48.8 STOP 9B Outcrop on left is rusty quartzose schist. Trail on right leads 1.8 miles to summit of Crotched Mountain. Outcrops of schist abundant for first three-fourths and last one-half miles. Near summit much of the schist has large aligned porphyroblasts of sillimanite. Type area of Crotched Mountain Member.

49.0 Junction, end of loop road. Go straight, toward Greenfield.

50.4 Stop sign. Turn left.

51.2 Greenfield. Turn right on route 136.

51.8 Bear right, sign for Hancock. Between this point and route 31 to north is a complex area of drift and outwash with kettle holes.

54.5 Covered bridge, Contoocook River.

55.7 Junction route 202. Go straight.

56.2 Bear left.

56.7 Junction route 123. Bear right. Outcrops of schist (a large inclusion) and quartz monzonite on right between here and 57.3.

57.3 Hancock. Bear left following route 123.

57.5 Turn left onto route 137.

57.9 Bear left onto Middle Road.

59.3 Turn right.

Mileage

60.2 STOP 10 Halfmoon Pond spillway. Built by the Army Engineers to divert flood waters to the Contoocook River below Peterborough. Glacially polished outcrops of Kinsman Quartz Monzonite. Large phenocrysts of microcline are flow aligned and later sheared. Outcrops slope towards water---use caution.

Go straight after stop.

60.6 Junction, road right to Sargent Camp. Go straight ahead. Outcrops of more "normal" Kinsman Quartz Monzonite to left and ahead to 61.1.

63.9 West Peterborough. T-Junction, turn left.

65.5 Peterborough, corner of Grove Street. A building here plus many foundations and retaining walls in Peterborough are made of a highly foliated binary granodiorite quarried across the Contoocook River only one-half mile south of here. This granodiorite is similar in composition to less foliated granodiorites in other parts of the quadrangle but has undergone cataclasis.

65.6 Cross Contoocook River, turn right.

66.3 Junction route 101. Turn left (east), toward Wilton and Milford.

70.0 Gap in Wapack Range between Pack Monadnock and Temple Mountains. Temple Mountain ski area to right. Road left leads 1.2 miles to Miller State Park at the top of Pack Monadnock Mountain. Abundant outcrops of schist, granite, and pegmatite along road and at summit; type area for Peterborough Member of Littleton Formation.

End of road log.

TRIP A-3

THE CARDIGAN PLUTON OF THE KINSMAN QUARTZ MONZONITE

John B. Lyons and Russell G. Clark
Dartmouth College
Hanover, N. H.

Introduction:

This trip traverses the Cardigan pluton of the Kinsman Quartz Monzonite (Billings, 1956, Plate 1), and examines outcrops of this formation, of its wallrocks, and of the younger intrusives cutting it. Billings (1956) has classified the Kinsman as a magmatic rock, and as a member of the Acadian-age New Hampshire Plutonic Series. Chapman (1952), however, has proposed that it is a granitized pelite. Thompson et al. (1968, p. 208) suggested an anatectic origin, the protolith possibly having been a volcanic unit within the Littleton Formation.

Petrology and Structure:

Megacrysts of potash feldspar up to 12 cm. in length and abundance of garnet characterize the Kinsman throughout most of the Cardigan pluton, but there are areas, chiefly those in which shearing has been important, where garnet is absent. Contrasting mineralogies in the Kinsman appear to be controlled by the reaction:

$$\text{musc.} + \text{bio.} + 3\ \text{q.} \rightleftharpoons 2\ \text{K. fs.} + \text{gar.} + 2\ H_2O$$

Ingress of water along shear zones drives the reaction toward the left; over most of the pluton, P, T, and a_{H_2O} are such as to favor the potash feldspar-garnet pair. Crystallization of garnet is induced by extremely low oxygen fugacity conditions, (cf. Hsu, 1968) which are caused by the widespread distribution of graphite within the Kinsman formation.

A close network of gravity stations over the portion of the Cardigan pluton visited in this excursion indicates that it is nowhere thicker than 2.5 km. We interpret the pluton to be a flat synorogenic sheet of contaminated magmatic rock which, when it had reached a semi-solid condition, was injected,

probably along shear zones, by flat-lying pegmatites and aplites. All of these early-formed rocks were involved in a cycle of westward-overturning and recumbent folding. Renewed (or continued) folding produced a set of N-NE trending folds and, locally, a vertical axial plane cleavage. Breakdown and replacement of garnet by biotite probably occurred at this time. Finally, the Kinsman was intruded by the Spaulding Quartz Diorite, the Concord Granite and late-stage pegmatities and aplites.

The spectacularly large potash feldspar megacrysts of the Kinsman Quartz Monzonite are considered to be phenocrysts on the following evidence: 1) early time of crystallization, as shown by extreme cataclasis, 2) inclusions of zoned plagioclase (An_{26-35}) and of biotite aligned parallel to the major crystallographic planes of the K-feldspar host, 3) clear x-ray evidence, despite their present predominantly triclinic symmetry, that the original K-feldspar symmetry was monoclinic, 4) K/Rb ratios in coexisting biotite and alkali feldspar from the Kinsman lower than those in the Littleton schist, and showing a progression toward the high Rb concentrations characteristic of differentiated magmatic series, and 5) appropriate bulk rock chemistry to account for the presence of potash feldspar phenocrysts.

Whether the Kinsman magma originated *in situ* or at deeper levels is uncertain. We favor the latter alternative because of 1) the pervasive graphitic contamination, 2) the evidence, from contact reaction zones and from Mg/Fe ratios in coexisting garnet and biotite, of a higher temperature of crystallization than that of the wallrocks (Lyons and Morse, 1969), and 3) local and areal cross-cutting relations of the Kinsman with respect to its wallrocks.

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MAPS

1. U. S. Geological Survey 15' Topographic Map of Mt. Kearsage, New Hampshire, Quadrangle, 1956.

2. Geologic Map and Structure Sections of the Sunapee Quadrangle, New Hampshire, Plate 1 *in* Chapman, C. A., 1952, Structure and petrology of the Sunapee quadrangle, New Hampshire. Geol. Soc. Am. Bull., v. 65, p. 381-425.

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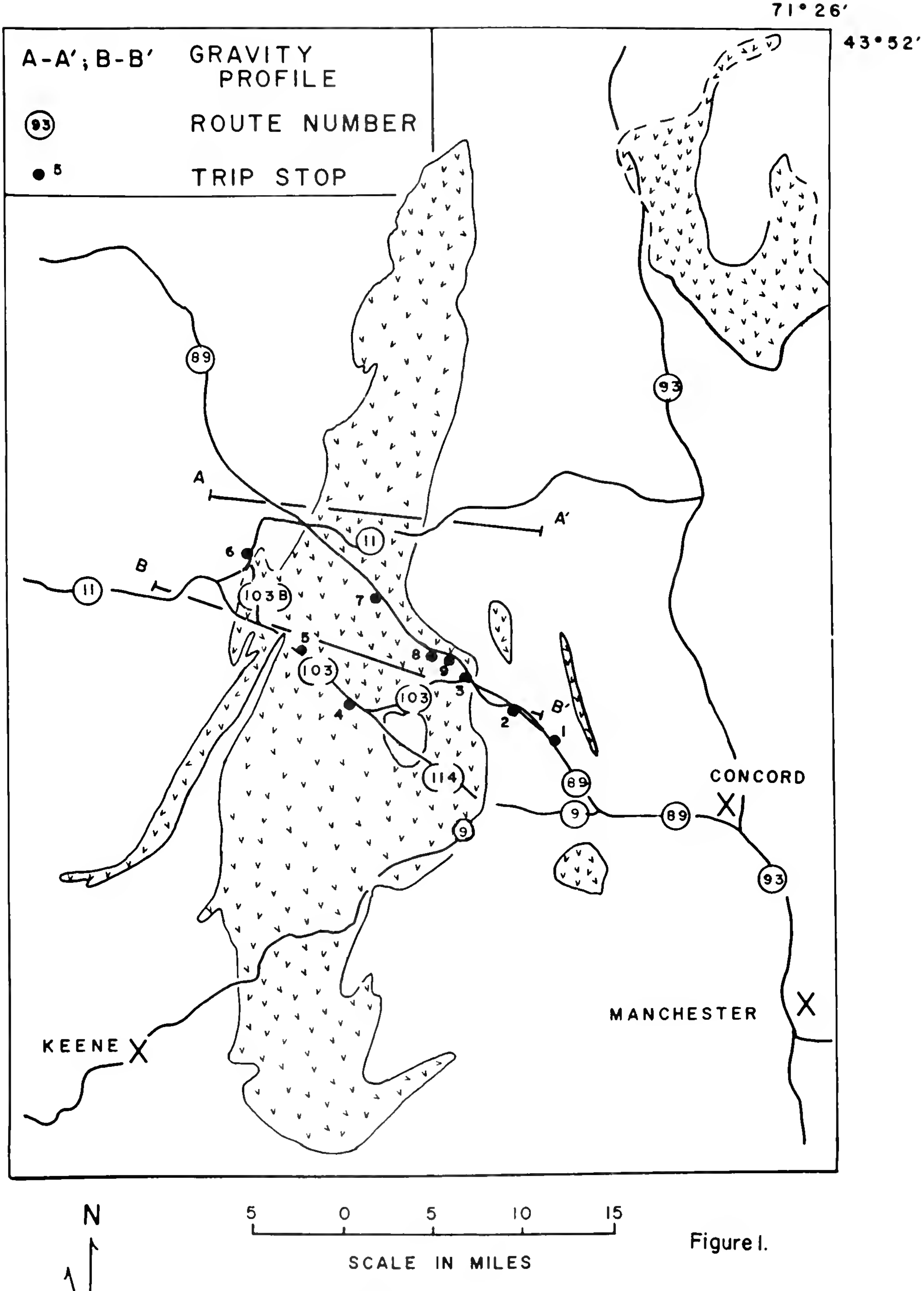

Figure I.

SKETCH MAP OF KINSMAN PLUTONS
WEST-CENTRAL NEW HAMPSHIRE
(after Billings, 1956)

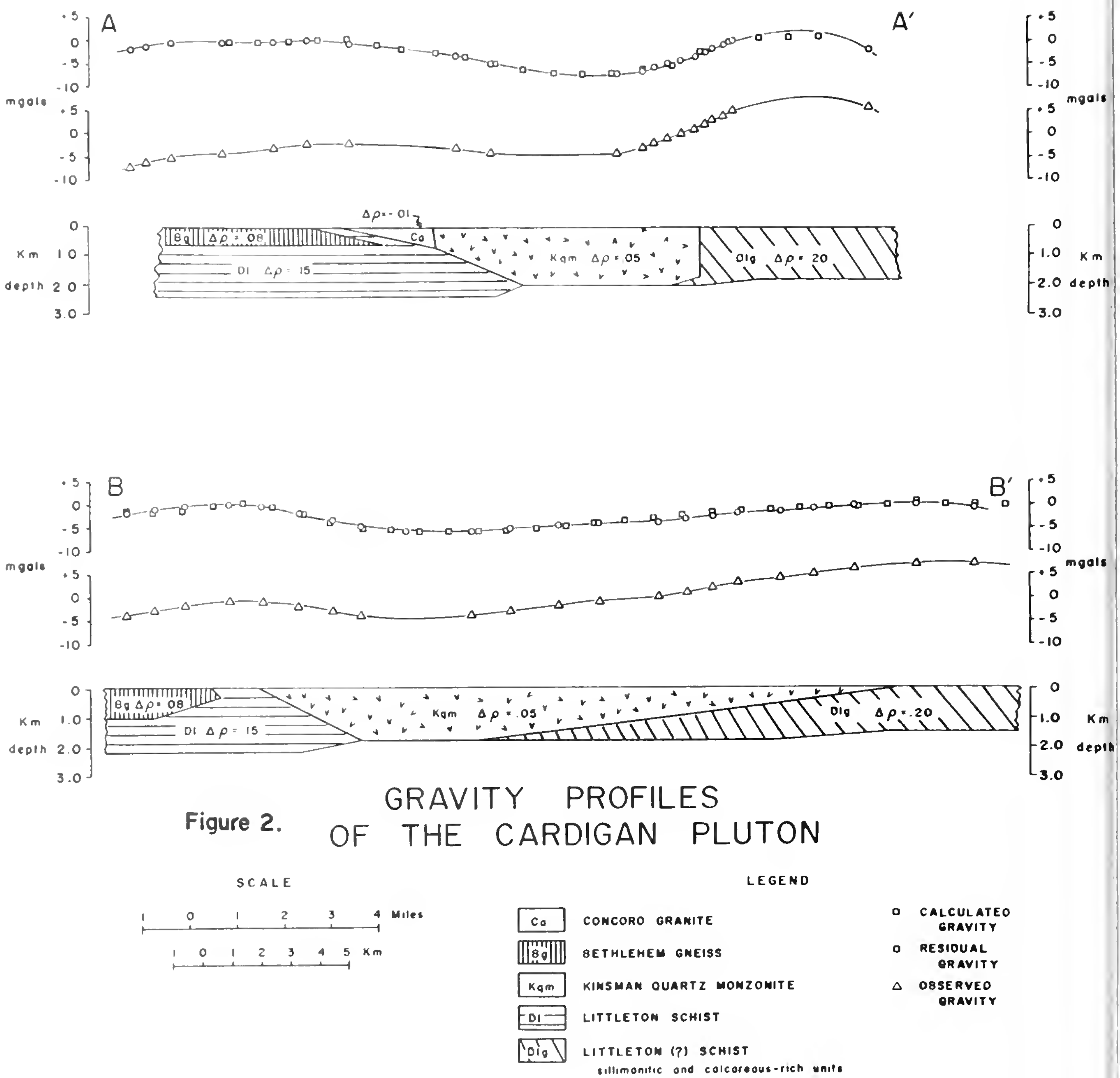

Figure 2. GRAVITY PROFILES OF THE CARDIGAN PLUTON

DATUM FOR GRAVITY READINGS IS ARBITRARY

RESIDUAL GRAVITY IS SIMPLE BOUGUER ANOMALY

ROAD LOG FOR TRIP A-3

Assemble at 8:00 AM at parking lot of New Hampshire Highway Motel in Concord. Heat south towards Routes 4 and 9.

Mileage

0.2 Stop light; turn right on Routes 4 and 9.

0.3 Turn left (south) onto Interstate 93.

3.1 Right (westerly) turn onto Interstate 89.

7.8 Rusty schists of the Littleton (?) Formation, intruded by biotite granite. Generalized Geologic Map of Northern Appalachians by Zen et al. (1968) projects Cambro-Ordovician schists (Partridge Formation?) to a point not far south of these outcrops.

11.7 Junction with Route 9. Continue northwesterly (right fork) on Interstate 89.

16.4 STOP 1 Littleton(?) Formation showning atypical lithologies, consisting of calc-silicate granofels, fine-grained quartz-feldspar-pyrrhotite granofels, and amphibolite. Sub-horizontal foliation in outcrop has axial plane relationship to northerly-trending recumbent folds, overturned toward the west.

20.7 Leave Interstate 89 on Exit 8, toward north.

21.0 Turn left toward village of Warner. Outcrops of calc-silicate granofels on right.

21.2 Left (easterly) turn onto Route 103, crossing Interstate 89.

21.7 STOP 2 Outcrop of calc-silicate rock. Boudins of grossularite-quartz are surrounded by diopside-actinolite zones, all within a biotite schist. Rocks are isoclinally folded along northerly-trending axes, and are overturned toward the west in a style which suggests a second deformation, or continuing deformation subsequent to overturning. Outcrop is injected by granite, by pegmatite, and by a garnet granodiorite related to the rocks of the nearby Cardigan pluton.

Turn around and proceed westerly on Route 103 through Warner Village.

24.9 STOP 3 Kinsman Quartz Monzonite, showing both garnetiferous and biotitic phases. Minor amounts of cordierite and sillimanite have been found in the Kinsman here, and the large potash feldspar megacrysts show their ubiquitously developed myrmekite rims. Biotite replaces garnet, but there is no petrographic evidence here for a reaction such as:

gar. + musc. $\rightleftharpoons$ bio. + sill. + q. Conversion of garnet to biotite may thus be a late-stage magmatic effect. Aplite intruding the Kinsman has been folded and faulted, and the potash feldspar megacrysts line up in the axial plane of one fold.

Gravity studies in the Cardigan pluton indicate that the maximum thickness of the Kinsman Quartz Monzonite is less than 2.5 km; at this outcrop it is less than 0.2 km. Although foliation dips steeply to the east, the wallrock envelope here slopes approximately 14° westward.

31.5 Intersection of Routes 114 and 103; continue west on 103. Outcrop on north side of road is Concord granite intruding Kinsman Quartz Monzonite.

32.6 STOP 4 Large road cut in the Kinsman, which here displays a sub-horizontal foliation, and is injected by pegmatite, aplite, and Concord granite. The notable feature here is the extensive development of 1 to 2 foot thick bands of garnet-plagioclase-quartz granofels. These bands, though on a smaller scale, are petrographically similar to the garnet ores mined in the past at various places in New Hampshire, but chiefly where there are large xenoliths of aluminous schist in the Kinsman.

35.8 Outcrops on both sides of road are similar to those at STOP 4, except that garnet ore occurs in an isolated pod, and the analyzed Kinsman here shows good evidence for the reaction:

garnet + potash feldspar + H_2O $\rightleftharpoons$ biotite + sillimanite + 2 quartz

37.2 Mountain Road goes off toward the left (south). A large fault zone on the southeast side of Mountain Road, 1/2 mile from Route 103 has yielded an illitic fault gouge (1Md muscovite) which is considered to be authignic. The K/Ar age on the illite is 157 ± 3 m.y. Two other similar fault zones in western N.H. have ages of 160±4 m.y.

37.4 STOP 5 Pre- and post-folding aplite, Concord granite, and pegmatite cutting the Kinsman. Garnetiferous and biotitic phases of the Kinsman are both extensively sericitized.

On the north side of the road, about midway along the outcrop, is a garnet granofels, separated from the rock to the west by a cordierite (65%)-plagioclase-phlogopite-sillimanite-garnet granofels.

40.4 Go left around traffic circle and enter road to Mt. Sunapee State Park.

41.4 Lunch stop.

42.2 Exit from Mt. Sunapee State Park, bearing left around traffic circle, and follow Route 103-B toward Sunapee village.

45.9 Turn right (northeasterly) at junction with Route 11.

46.2 STOP 6 Spaulding Quartz Diorite, intruded by pink pegmatite. Elsewhere (but not at this outcrop) it may be shown that the Spaulding intrudes the Kinsman.

The unusual feature of this outcrop is gneissic agmatite containing fragments of schist, vein quartz, pegmatite, aplite, and potash feldspars similar to those in the Kinsman. Pink potash feldspar xenocrysts in the agmatite create a special problem, because pink pegmatite dikes clearly cut the agmatitic rock. The outcrop is thought to represent a fluidized explosion vent which served as a channelway for the pegmatitic fluids. The xenoliths and xenocrysts presumably originate at deeper levels, but their precise site of origin is uncertain.

Continue on Route 11 through George's Mills toward New London.

51.2 Turn right (south) onto Interstate 89.

51.8 Large outcrop of Concord granite, intruded by a lamprophyre. Concentrations of autunite occur near the dike.

58.2 STOP 7 Kinsman, intruded by aplite and pegmatite, which have been folded along a N38E axial trend; some minor folds, however, are disharmonic, either owing to later folding, or to an inhomogeneous response of the rocks to deformation. A large xenolith (?) of schist (?) is of interest here. Note that it contains deformed K-feldspars similar to those in the Kinsman, and that myrmekitization post-dates cataclasis of the feldspars. Garnet in the Kinsman has been completely pseudomorphed by biotite.

63.9 STOP 8 Aplite dike, which becomes progressively boudined, and finally shredded as it passes into the nose of a tight recumbent fold. The schistose rocks here grade into the Kinsman, but the transition is thought to represent progressive cataclasis, rather than the transformation of Littleton schist into Kinsman-type rocks. Note the resemblance of the schistose rocks here to the xenolith (?) of Stop 7.

64.5 STOP 9 Spotted (fleckly) gneiss of the Littleton formation, showing garnet nuclei surrounded by microcline rims, the texture probably resulting from reaction and breakdown of biotite + muscovite.

The Kinsman enclosing the schists here is a granodiorite similar to that at Stop 2, containing the assemblage q-K.fs.-plag.-bio.-gar.-cord.-sill.-il.-ru.-sulfides. According to Schreyer and Seifert (1969) this assemblage suggests temperatures $\sim$695°C, and pressures $\sim$5 kb.

END OF TRIP. RETURN TO CONCORD (22 MILES) ON INTERSTATE 89.

TRIP A-4

GEOLOGY OF MASCOMA MANTLED GNEISS DOME NEAR HANOVER, NEW HAMPSHIRE

Richard S. Naylor
Department of Earth and Planetary Sciences
Massachusetts Institute of Technology, Cambridge, Mass.

Introduction

This trip will show the core and mantle rocks of the Mascoma Dome, which is one of the best examples of the Oliverian belt of mantled gneiss domes. The trip will emphasize the geological features which led me to reinterpret the core rocks of the domes as part of an Ordovician Volcanic and intrusive complex--possibly an island arc.

The stratigraphy of the area is the classical Littleton (youngest), Fitch, Clough, Ammonoosuc sequence of Billings (1937). My work has added a new stratigraphic unit called "Holts Ledge Gneiss" or "stratified core-rock of the Mascoma Dome" below the Ammonoosuc Volcanics. The area has been mapped at inch to the mile scale by Chapman (1939: Mascoma Quadrangle) and Hadley (1942: Mt. Cube Quadrangle). These authors should be consulted for detailed descriptions of the units. My field and geochronologic data and the resulting interpretations are given in two papers (Naylor, 1968; 1969). The latter summarizes the Mascoma area geology and geochronology and reviews the general mantled gneiss dome problem. It is called to your attention in lieu of a general discussion in this guidebook.

A New Hampshire road map and copies of the Mascoma and the Mt. Cube 15 minute quadrangles will be useful on the trip.

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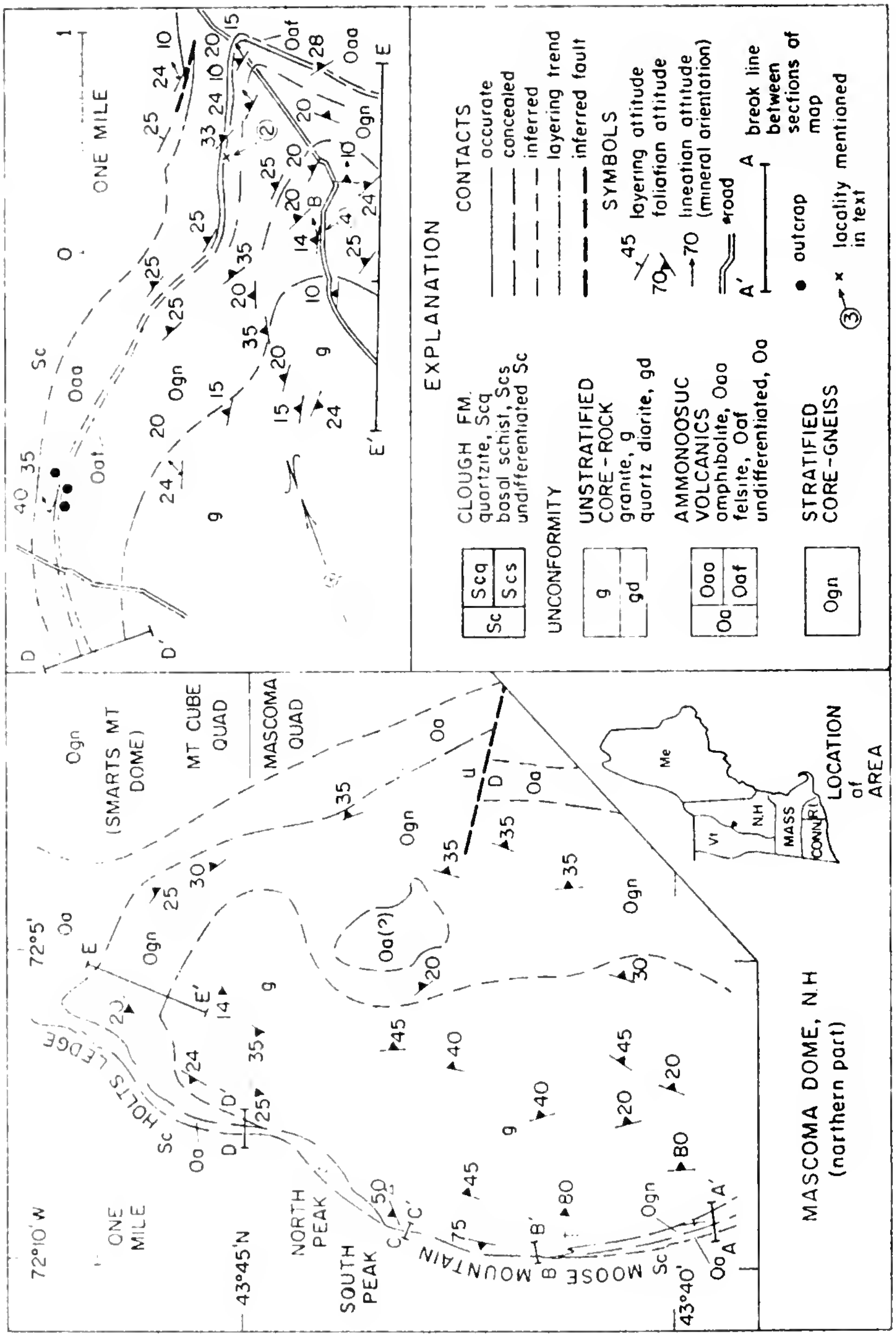

Figure 1. Geologic map of northern part of Mascoma Dome. Generalized geologic map (modified from Chapman, 1939, and Hadley, 1942) showing location of detail maps. Detail geologic map of northern end of dome.

After R. S. Naylor, 1969, Geol. Soc. America Bull., v.80, p.407

Figure 1.

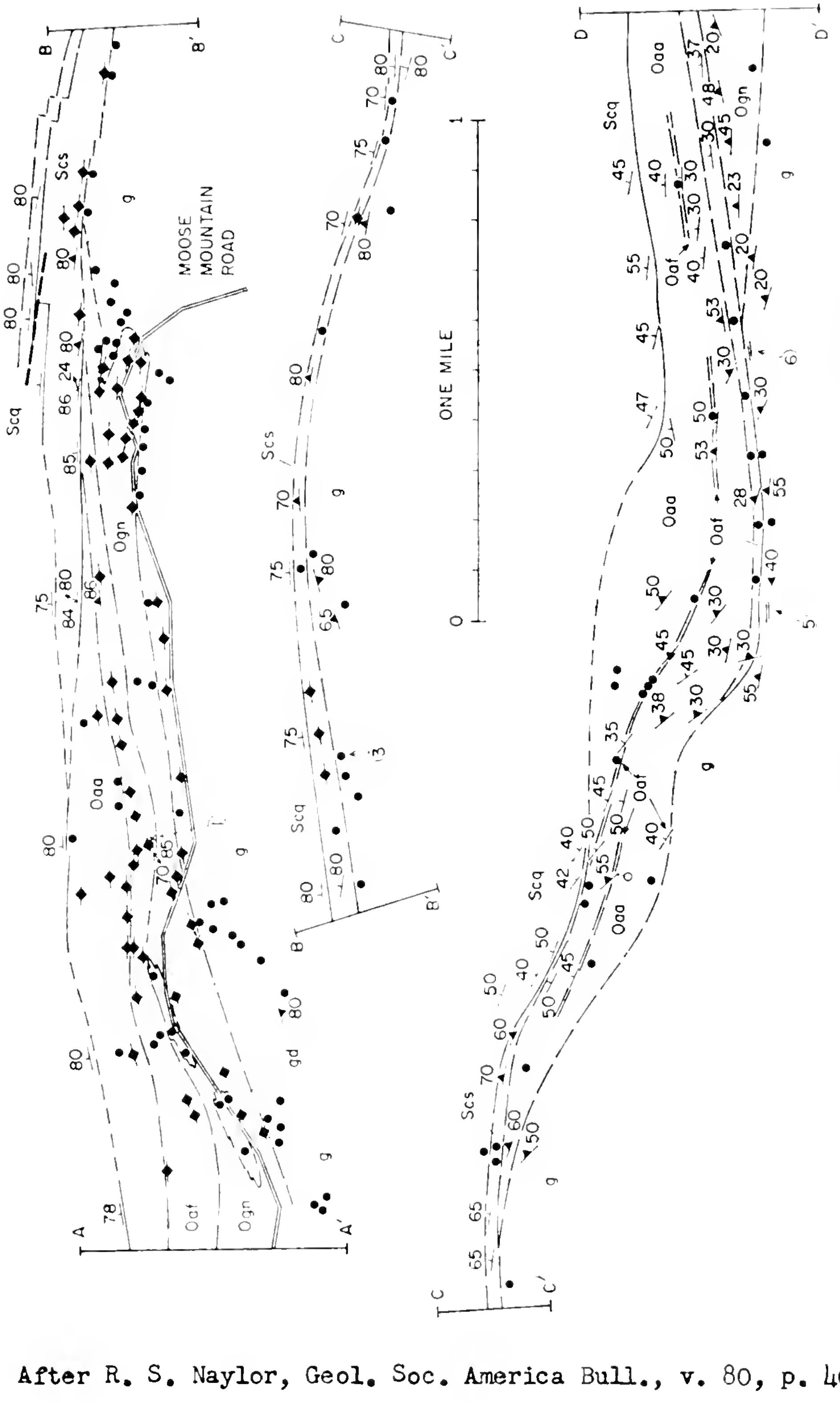

Figure 2. Geologic maps of western margin of Mascoma Dome. For location of maps and explanation see Figure 1

After R. S. Naylor, Geol. Soc. America Bull., v. 80, p. 408

Figure 2.

ROAD LOG FOR TRIP A-4

Assembly Point

DARTMOUTH SKIWAY, Lyme Center, New Hampshire.

Try to be at STOP 1A by 9:40 AM. This means leaving CONCORD by 8:00.

From Concord, New Hampshire, take Interstate 89 north to to exit 18; thence NH 120 to Hanover; NH 10 north to Lyme. On the north side of the village of Lyme turn right on the unnumbered paved road east leading east through Lyme Center toward the Dartmouth Skiway. 1.2 miles east of Lyme Center fork right and follow the blacktop into the parking lot of the Dartmouth Skiway. Lock up. Walk south past the Lodge to the base of the beginners slope (southermost ski trail) on the west side of the road. Hike up to STOP 1A; lift-head at top of the beginners slope.

The mantle and stratified core-rocks of the Mascoma Dome are well exposed on the facing cliffs of Holts and Winslow Ledges. We will traverse up-section, scrambling up a succession of low cliffs separated by terraces parallel to bedding (presently utilized as ski trails). Southward these terraces vanish, merging the cliffs into a sheer 200-foot face of rather crumbly rock. (Mr. Ronald Kley of Boston University recently solved the problem of sampling these cliffs by resorting to a 20 mm cannon with armor-piercing shells.) Please watch your traverse on the cliffs so you do not get hung-up or worse; the ski trails provide alternate access to all exposures. The route will take about 2 hours; the highest point is about 800 feet above the cars.

STOP 1A Lift-tower at head of beginners' slope; Holts Ledge.
The outcrop at the lift-head is rich in potassium feldspar. I interpret it as a metamorphosed rhyolite. The cliffs below the lift (east) are massive quartz-plagioclase-biotite-hornblende gneiss mapped as stratified core-rocks of the Mascoma Dome. It is worth scrambling down to see the coarse compositional layering which is well displayed at this locality. The prominent mafic layer can be traced for several hundred yards. From this layering and the quartz-rich composition of the rocks, I have concluded the unit is volcanic--probably mostly water-laid tuff. The biotite-rich schlieren may have resulted from metamorphism of glassy bombs, which altered to celadonite shortly after deposition. Perhaps the characteristic platy aggregates of fine biotite are the remains of altered glassy lapilli.

The stratified core-gneiss grades upwards into the Ammonoosuc Volcanics. Compositional layering in the two units is parallel, but the Ammonoosuc is more mafic and perhaps consistently finer grained. I have arbitrarily mapped the contact along the surface above which the mafic layers constitute more than 50 percent of the section. This is generally consistent with the criteria applied by other workers. There is no harm in considering the stratified core-gneiss as a lower member of the Ammonoosuc Volcanics. Owing to the controversy over its origin and since it is a distinctive lithological unit, I prefer to treat the Gneiss unit as a separate formation, to which I have informally applied

the name Holts Ledge Gneiss. Unfortunately, in print I was persuaded to use the more cumbersome name, "stratified core-gneiss of the Mascoma Dome".

STOP 1B Cross up to next higher ski trail--Don Worden's Schuss; proceed about 70 yards uphill, then scramble down over first ledges at a feasible place. The contact between the Ammonoosuc Volcanics and the stratified core-gneiss is mapped about 10 feet below the bedding surface on which this part of the schuss is laid. The fine-grained, sulfidic meta-basalt is mapped in the Ammonoosuc.

STOP 1C 50 yards further uphill the schuss takes an abrupt upturn to the right. Just before this, on the uphill side of the trail, are good cliff exposures of AMMONOOSUC VOLCANICS. The lower ledges display alternating thin layers of felsic and mafic gneiss and granulite. Higher up are ledges of thin-layered mafic epidote-amphibolite characteristic of the Ammonoosuc in the dome belt. Note the epidote nodules and the quartz tourmaline veins.

With a small party it is instructive to climb hand over hand up the complete series of ledges to the Poma Lift. With a group of more than 6 people it is better to back-track and continue the climb via the schuss.

STOP 1D The ski trails converge at the head of the Poma Lift. From here it is a 50-yard walk up a cleared slope to the overlook at HOLTS LEDGE. Panoramic view. The flat-topped mountain NE with a fire tower is Smarts Mountain. Felsic gneiss similar to the stratified core-rock of the Mascoma Dome is exposed on the steep west face, this being the next "Oliverian" dome. The firetower is rooted in Ammonoosuc volcanics which have not yet been eroded from the central and eastern parts of the dome. Mt. Cube, capped by Clough Quartzite, is the more distant mountain to the left, shaped like a truncated pyramid.

The fence is there with good reason. In dry weather it is safe to go beyond the fence, BUT PAY CLOSE ATTENTION TO THE EDGE--it is 200 feet down. Good exposures of Ammonoosuc Volcanics at the crest.

About 50 yards along the D.O.C. Trail to the south is another overlook. The larger lake to the south is Goose Pond in the center of the Mascoma Dome. A foreshortened view of the cliff containing the contact can be seen by looking back to the north. More than six people cannot occupy this second overlook at one time. PLEASE WATCH YOUR STEP!

STOP 1E Descend by way of the second trail west (left) of the Poma Lift. This trail follows the surface of the unconformity between the Ammonoosuc Volcanics and the Clough Formation. Several outcrops of the latter are readily accessible near Holts Ledge Cabin (D.O.C.) about halfway down.

Return to cars in parking lot for LUNCH.

0.0 Fork in road about 1.5 miles north of Robert Peter Brundage Ski Lodge.

1.2 Lyme Center. LEFT TURN at store, cross bridge, and proceed up steep hill.

2.9 Former Chesley School on left.

3.5 FORK RIGHT on upper road.

4.5 STRAIGHT through cross road, continue up steep hill.

5.9 MERGE with ETNA road (paved), continue south. You are now in MASCOMA QUADRANGLE for rest of trip.

8.2 Cemetery in Hanover Center.

9.8 Cemetery on right.

10.1 Church on left. LEFT TURN at junction 0.1 mile beyond church.

11.8 STRAIGHT at junction, cross bridge.

12.3 LEFT on dirt road which dips steeply; blacktop curves right just beyond turn.

12.7 STOP 2 at dirt road on right, park north of house and red barn. Squeeze into as few cars as possible, park and lock the others. Do not block either road.

Drive up dirt road towards WHED-TV tower. At top of Moose Mountain (about 0.7 mile) take right fork; park near houses 0.2 miles south.

Walk to end of road beyond second house. Continue south along cow-path through pasture. Path climbs past ledges of CLOUGH quartzite. Uphill through open orchard at south end of pasture into upper meadow. Continue to top of hill at south end of upper meadow. In open woods to the south are basal beds of Clough quartzite. Immediately east are exposures of weathered muscovite-bearing granite. The granite lies unconformably beneath the Clough. Weathering below the unconformity probably led to an enrichment in Al which became muscovite after Acadian regional metamorphism.

Chapman (1939) mapped a large bulge of granite cutting the Clough one mile north of this stop. His map is in error due to faulty base-map topography. Detailed mapping shows no beds of Clough cut by the granite.

12.7 Return to parked cars. Turn around. Go back out the way we came in.

13.2 LEFT TURN onto blacktop heading south.

16.7 LEFT TURN onto US 4 heading east. Watch stop sign.

18.1 Village of Enfield. Stay on US 4 as it winds to the left.

18.3 LEFT TURN onto Moose Mountain Road at crossroads (at bottom of hill 0.15 mile past Elementary School on left). If you pass Baltic Mills you have gone .5 mile too far on US 4.

18.4 FORK LEFT up hill.

21.4 Road enters woods. This will be Stop 4. Continue straight for Stop 3.

21.8 STOP 3 At trail on right. Park cars so as not to block main road. Lock up.

Follow the trail (right fork about 50 yards east from the road) about 1/2 mile uphill to the abandoned MOOSE MOUNTAIN quarry. This is the quarry shown on most editions of the topographic map.

Contrast the massive character of the quarry rock with the coarsely stratified character of the rocks at Stop 1A. The structure and texture of the rock, its chemical composition, its crosscutting relationships with the stratified rocks, and the aplite and pegmatite veins indicate that the rock is intrusive. The intrusion was probably shallow. Note the presence of magnetite (in well developed octahedra--probably primary) coexisting with biotite and microcline. D. R. Wones (personal communication, 1967) suggests this indicates P_{H_2O} was less than 1.5 kb when the magma crystallized (at higher water pressure all of the Fe could be stable in biotite). The aplite veins indicate that the total pressure was less than P_{H_2O} in the late stages of intrusion--hence, shallow intrusion. This is consistent with the unroofing relationships discussed at Stop 2.

Clough Quartizite unconformably resting on granite supports Moose Mountain, the prominent ridge 1 km west. The granite constitutes the upper part of the intrusive body. Structurally lower intrusive rocks are quartz monzonite. Being somewhat more mafic, they erode more readily and underlie the lower ground east of the granite hills.

Rock from this small quarry was probably used mostly for local construction of foundations and stone walls. A larger quarry in similar rock two miles south (one mile east of Enfield Reservoir) yielded exportable constructional granite used in the Tercentennial monument, Jamestown, Virginia; Plain Dealer Building, Cleveland, Ohio; Carnegie Institute, Pittsburg, Pennsylvania; and Royal Bank of Canada, Winnipeg, Manitoba (Dale, 1923, p. 178).

21.8 Return to cars. Turn around and proceed back the way you came in.

22.2 Road leaves woods, curves left.

22.3 STOP 4 Park cars in front of cabin so as not to block road or drive.

This area is a critical one for working out the relationships between the major rock units in the dome. Significant ourcrops are scattered through about 300 acres of dense brush, but fortunately most of the units are well expressed in the topography, so we can see things from the road.

An unusually mafic phase of the stratified core-geniss ("Holts Ledge Gneiss") is exposed along the road. More felsic gneiss crops out in the fields to the west. The mafic Ammonoosuc Volcanics start further west at the break in slope back of the tree line. The steep slope is covered with talus of Clough Quartzite which crops out nearly continuously along the ridge crest (Moose Mountain)--in other words, the normal stratigraphic succession for the area.

The line of hills to the east is underlain by granite, the first outcrops of which occur about 50 yards east of the road beyond the row of trees. From here south to beyond Stop 5, the contact between the granite and the stratified core-gneiss is roughly concordant.

Immediately north of Stop 4, the granite contact swings abruptly west cutting across the stratified core-gneiss, until the granite eventually comes in contact with the Clough Quartzite where we saw it at Stop 3 (one mile north of here). The Ammonoosuc Volcanics pinch out somewhere in a zone of no exposure. Aplitic veins are abundant in the stratified core-gneiss near the granite.

The field relationships indicate that the Clough Quartzite rests unconformably on all of the older units. The granite is younger than the stratified core-gneiss, but older than the Clough. The relationship between the granite and the Ammonoosuc Volcanics is uncertain here.

Continue south.

22.9 Farmhouse on right.

23.4 STOP 5 Farm with barns to right and left. Park so as not to block any roads. Walk back (north) to curve in road.

This stop shows a concordant stretch of contact between the granite (unstratified core-rock of the Mascoma Dome), and the Holts Ledge Gneiss (stratified core-rock). Granite, slightly more mafic than usual, is exposed in the bend of the road. Note the large aplite vein. Thirty feet south is a large exposure of mafic stratified core gneiss. Note the large epidote nodules and the aplitic veins. The veins were probably originally granite, but the potassium has subsequently reacted into the mafic gneiss. This contact can be traced for several miles locally and is essentially concordant. The Ammonoosuc Volcanics begin at the break in slope beyond the tree line uphill.

<u>END OF TRIP</u> - Continue south back to Enfield Village. Concord and Boston via US 4; make left turn on US 4 at crossroads.

<u>OR</u>

Right on US 4; proceed about 5 miles west to Interstate 89 at exit 17; south for Concord and Boston. For Connecticut and New York, go north on 89 five more miles to Interstate 91 South.

To eat, try Riverside Grill off US 4 at 89 exit 17. Either route to Concord is about the same travel time.

TRIP A-5

SOUTHWEST SIDE OF THE OSSIPEE MOUNTAINS, NEW HAMPSHIRE_/

Lincoln R. Page
U.S. Geological Survey
Boston, Massachusetts

Two short traverses will be made across the outer ring of the Ossipee Mountains ring dike structure on either side of the Tuftonboro-Moultonboro town line to see the Albany Porphyritic Quartz Syenite of the White Mountain Plutonic Series and the Moat Volcanics as well as the enclosing rocks. Stops will also be made enroute to see the Kinsman Quartz Monzonite and associated dike rocks and Winnipesaukee Quartz Diorite of the New Hampshire Plutonic Series.

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_/Publication authorized by the Director, U.S. Geological Survey.

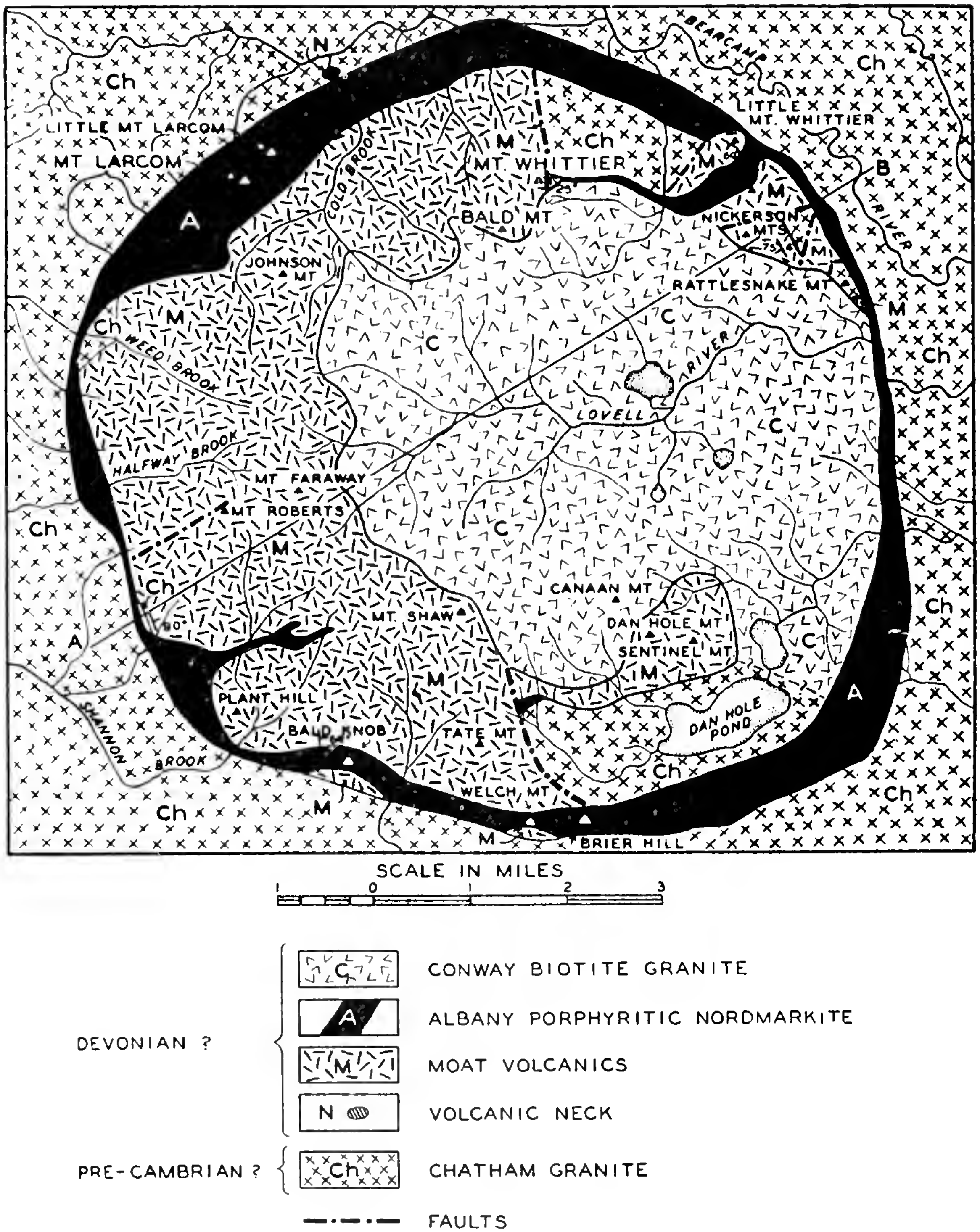

Figure 1. Geologic Map of the Ossipee Mountains
After Louise Kingsley, 1931, Am. Jour. Sci., v. 222, p. 141

ROAD LOG FOR TRIP A-5

Milage

0.0 Intersection of Interstate 93 and State Route 9, New Hampshire Highway Motel, Concord, N. H. Take Interstate 93 north. Outcrops along Interstate 93 are Silurian and Devonian schists cut by younger pegmatites.

30.7 Exit 23 (Meredith-Bristol exit); take Routes 3B and 104 east to Meredith.

31.4 Intersection of Routes 104 and 3B. Take Route 104 east (straight ahead).

31.8 Outcrops of Kinsman Quartz Monzonite.

32.8 Outcrop of Kinsman cut by mafic dike rocks.

35.6 STOP 1 Outcrop of Kinsman Quartz Monzonite showing primary foliation, abnormally large feldspar phenocrysts, inclusions or screens of Devonian schist, and a variety of granitic and pegmatitic dike rocks with and without primary foliation.

39.4 Intersection of Routes 104 and 3. Take Route 3 north (left).

40.4 Intersection of Routes 3 and 25 at Meredith. Take route 25 east (right).

44.2 Outcrop similar in lithology to the Concord Granite.

45.2 Center Harbor, intersection of Routes 25 and 25B. Take Route 25 east (straight ahead).

45.8 STOP 2 Outcrop of Winnipesaukee Quartz Diorite showing primary foliation and scattered lenticular feldspar phenocrysts in one of the more potassic facies of the pluton.

50.1 Moultonboro, intersection of Route 25 with Route 109 north. Take Routes 25 and 109 east (straight ahead).

50.2 Leave Route 25. Take Route 109 south (right).

52.8 Intersection of Routes 109 and 171. Take Route 109 south (right).

57.0 STOP 3 Panorama of area to be studied on Ossipee Mountains and discussion of rock types and structure.

57.1 Intersection, turn east (left).

57.7 Intersection, turn north (left).

58.6 STOP 4 Intersection with Route 171. Turn east (right) across bridge and park. Traverse up brook, about half a mile across contact of Winnipesaukee Quartz Diorite and Albany Porphyritic Quartz Syenite. Features to be observed include: 1) Winnipesaukee Quartz Diorite containing granitic and pegmatite dikes and mylonite streaks on minor faults in wall of ring dike structure; 2) Winnipesaukee Quartz Diorite screens in Albany Porphyritic Quartz Syenite; 3) Albany Porphyritic Quartz Syenite in outer ring of structure cut by mylonite streaks, in contact with wall rock screens and Moat Volcanics of subsiding block; 4) change in grain size, quartz content, and color of feldspars in syenite relative to contacts; and 5) petrographic variations in the Moat Volcanics.

58.6 Turn around and take Route 171 north.

60.4 Gate lodge and entrance to Castle in the Clouds. Take private road up mountain. (If you are taking this trip independently you must pay a fee of $1.75 and arrange with owners to stop en route.)

60.5 STOP 5 Outcrop of Kinsman Quartz Monzonite in brook cut by Concord-type granite. Both have primary foliation. Next outcrop up brook shows a variety of rocks and age relations including: 1) inclusions of Devonian schist; 2) several varieties of intrusive rocks and migmatites(?) of the New Hampshire Plutonic Series, both syn- and post-tectonic (Acadian); 3) amphibolitic beds; and 4) very feldspathic Kinsman Quartz Monzonite cut by 1-inch light-colored dike of the ring dike sequence.

60.6 STOP 6 Outcrop of black Moat Volcanics in brook with contact of Albany Porphyritic Quartz Syenite. Features to note include: 1) variation of phenocryst content and epidote clots in Moat Volcanics; 2) apophyses of Albany Porphyritic Quartz Syenite with glassy selvages cutting the Moat Volcanics; 3) pink feldspars and black ground mass of outer part of the Albany; 4) granite and other inclusions decreasing in abundance inward from the outer contact of the Albany Porphyritic Quartz Syenite; and 5) dip of the contact and related columnar jointing.

61.0 Glacial erratic of syenite from the North Conway region.

61.1 STOP 7 Short walk up trail to falls. First outcrop in brook contains granitic inclusion in Albany as at Stop 6. None known between stops 6 and 7. Dike of Albany cutting Albany. Traverse upstream to contact of Albany with amygdaloidal Moat Volcanics. Albany shows decrease in grain size and increase in pink feldspar toward intrusive contact with Moat. Several dikes of Albany in Moat are cut by dark greenish dike rock at the base of the falls. This dike rock is an offshoot of the matrix of the breccia that forms the diatreme exposed above the falls at the next stop. Several similar dikes cut the Moat in this area.

61.3 Glacial erratic of same type as at 61.0.

61.4 STOP 8 Albany Porphyritic Quartz Syenite showing banding, ignimbrite structures, and inclusions of Moat Volcanics.

61.6 STOP 9 Downhill to brook. Outcrop of small diatreme containing blocks of all rock types known in the immediate area plus plutonic rocks with no known exposures. Uphill side of diatreme cut off by fault.

Return to road and take trail upstream about 1/4 mile to outcrop of Moat Volcanics showing light-colored bands or segregations cut by intrusive breccias.

62.2 STOP 10 Parking lot. Walk up road to Castle in the Clouds. Outcrops show various types of inclusions and ignimbrite structures. These are best seen in the rock walls of the castle. The granite trim at the doorway of the castle is from the Conway Granite mass in the center of this ring structure. This rock has a primary foliation as distinct from the Conway Granite at the Redstone quarry in North Conway, N. H. From the castle one can see the ring structures of Red Hill and the Belknap Mountains, the fault scarp of the structure that cuts off the diatreme, and outcrops of Albany-type rocks within the Moat Volcanics mass.

From the parking lot, well-developed glacial channels can be seen in the fields to the north.

64.0 Re-enter Route 171. Turn north 1/2 mile to intersection of Routes 171 and 109 (or south 1.7 miles to gate lodge of Castle in the Clouds). Return to New Hampshire Highway Motel.

TRIP A-6

RECUMBENT AND RECLINED FOLDS OF THE MT. CUBE AREA NEW HAMPSHIRE - VERMONT

Douglas Rumble III
Geophysical Laboratory
Carnegie Institution of Washington

Introduction

The purpose of the field trip is to study the outcrop pattern and minor structures of recumbent and reclined folds believed to be northern extensions of the Skitchewaug Nappe (read Thompson, et al., 1968, for necessary background material). The rocks exposed in the folds also afford an opportunity to identify the mineral assemblages of pelitic schists, quartzites, calc-silicate rocks, and amphibolites regionally metamorphosed to kyanite-staurolite grade. The trip consists of two 1 1/2 mile woods traverses; there will be no roadcut stops. The traverse across the Jacobs Brook recumbent syncline utilizes lumber roads through open woods. The Wilmot Mountain traverse is a strenuous hike through thick underbrush and blow-down.

Acknowledgements

The field work on which the field trip is based was done under the direction of Professors J. B. Thompson, Jr., M. P. Billings, and John Haller, while the writer was a graduate student at Harvard University. Professor John B. Lyons made available laboratory facilities at Dartmouth College and contributed to many field conferences during the course of the work. Messrs. J. C. Hepburn, G. Patterson, A. C. Hine, and D. Walker assisted in the field work.

Stratigraphy

The uncomformity between the Pre-Silurian and Siluro-Devonian rocks is folded by the Jacobs Brook recumbent syncline and by the Wilmot Mtn. reclined fold. The Pre-Silurian rocks exposed in the limbs of the Jacobs Brook recumbent syncline are hornblende amphibolite and quartz-feldspar-biotite gneiss of the Middle Ordovician Ammonoosuc Volcanics. The Partridge Formation,

found overlying the Ammonoosuc Volcanics in other areas, is absent. Quartz conglomerate, quartzite, and quartz-mica schist of the late Early Silurian Clough Formation as well as marble, calc-silicate granulite, and biotite schist of the Late Silurian Fitch Formation occupy the core of the recumbent syncline.

Pre-Silurian rocks of the Wilmot Mountain reclined fold include horblende amphibolites and amphibolites with assemblages of colorless and pleochroic amphiboles. These rocks belong to the outcrop belt of the Post Pond Volcanics of the Orfordville Formation (read Hadley, 1942, for a complete review of previous work in the Mt. Cube area) and are possibly correlative with the Ammonoosuc Volcanics. Quartz conglomerate of the Clough Formation and calcareous schist of the Fitch Formation lie at the base of the Siluro-Devonian succession. Mica schists of the Lower Devonian Littleton Formation are the youngest rocks exposed in the reclined fold (read Rumble, 1969a, 1969b, for the justification of correlating these rocks with the Siluro-Devonian section).

Structure

The Siluro-Devonian rocks of the Mt. Cube area record at least two periods of pervasive folding. The older of the two sets of folds are recumbent and reclined folds such as the Jacobs Brook recumbent syncline and the Wilmot Mountain reclined fold (Figure 1). The younger folds are upright folds such as the NNE-trending Cottonstone Mountain and Bronson Hill anticlinoria (Figure 1).

The Jacobs Brook recumbent syncline lies in the mantle of the Smarts Mountain dome, one of a series of gneiss domes that together make up the Bronson Hill anticlinorium. It is evident from the hook-shaped outcrop pattern of the recumbent syncline that it has been refolded by the NNE-plunging Smarts Mountain dome (Figure 1, Figure 2). The minor folds of the Jacobs Brook area consist of an older and a younger group. The older group of folds is parasitic to the recumbent syncline and is of reclined or recumbent orientation. The younger group of folds is of upright orientation and is parasitic to the Smarts Mountain dome.

The Wilmot Mountain reclined fold is exposed in the west limb of the Cottonstone Mountain anticlinorium (Figures 1 and 3).

The older minor folds of the Wilmot Mountain area are of reclined orientation and have an axial surface schistosity. Younger, upright folds in schistosity are parasistic to the Cottonstone Mountain anticlinorium. The Wilmot Mountain reclined fold was tilted into its present position at the same time that the Jacobs Brook recumbent syncline was refolded by the Smarts Mountain dome. It is also probable that the Jacobs Brook recumbent syncline and the Wilmot Mountain reclined fold were formed at the same time.

Regional Metamorphism

Although the pelitic schists of the Jacobs Brook recumbent syncline and the Wilmot Mountain reclined fold are kyanite- and staurolite-bearing, they belong to different metamorphic subfacies. The quartz-muscovite schists of the Jacobs Brook recumbent syncline are characterized by the incompatibility of kyanite and biotite. Mineral assemblages such as staurolite-chlorite-biotite, and kyanite-chlorite-staurolite occur instead. In contrast, the assemblages kyanite-staurolite-biotite and kyanite-staurolite-garnet-biotite are common in the quartz-muscovite schists of Wilmot Mountain.

The porphyroblastic minerals of both areas are usually oriented with their longest dimensions lying in the plane of the schistosity which is parallel to the axial surfaces of the older folds. Recrystallization was not, however, limited to the older period of deformation because the folded schistosity and rotated porphyroblasts of the younger folds show no cataclasis.

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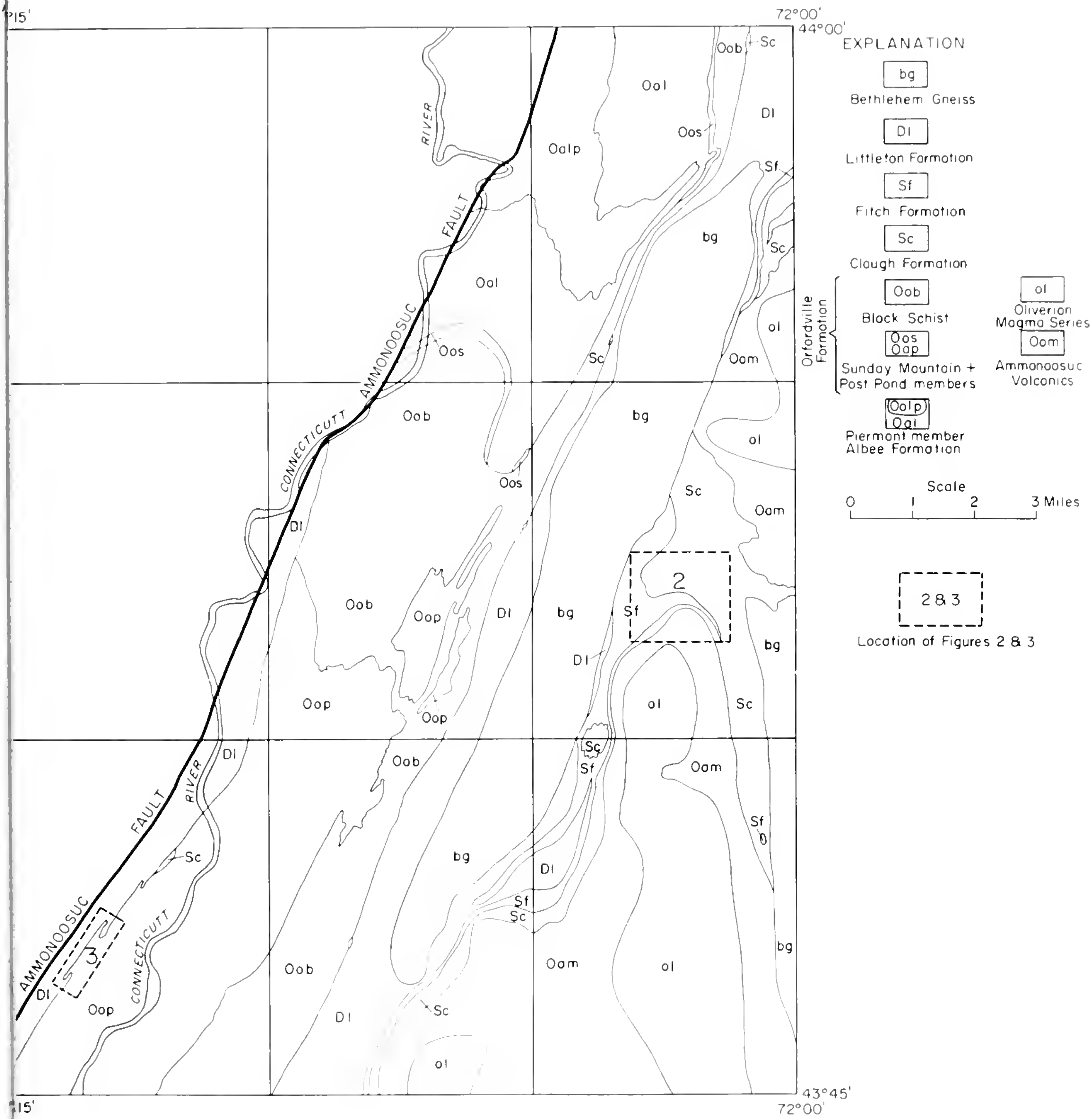

Figure 1 Geologic Map of the Rocks East of the Ammonoosuc Fault, Mt. Cube Quadrangle (after Hadley, 1942 and Rumble, 1969)

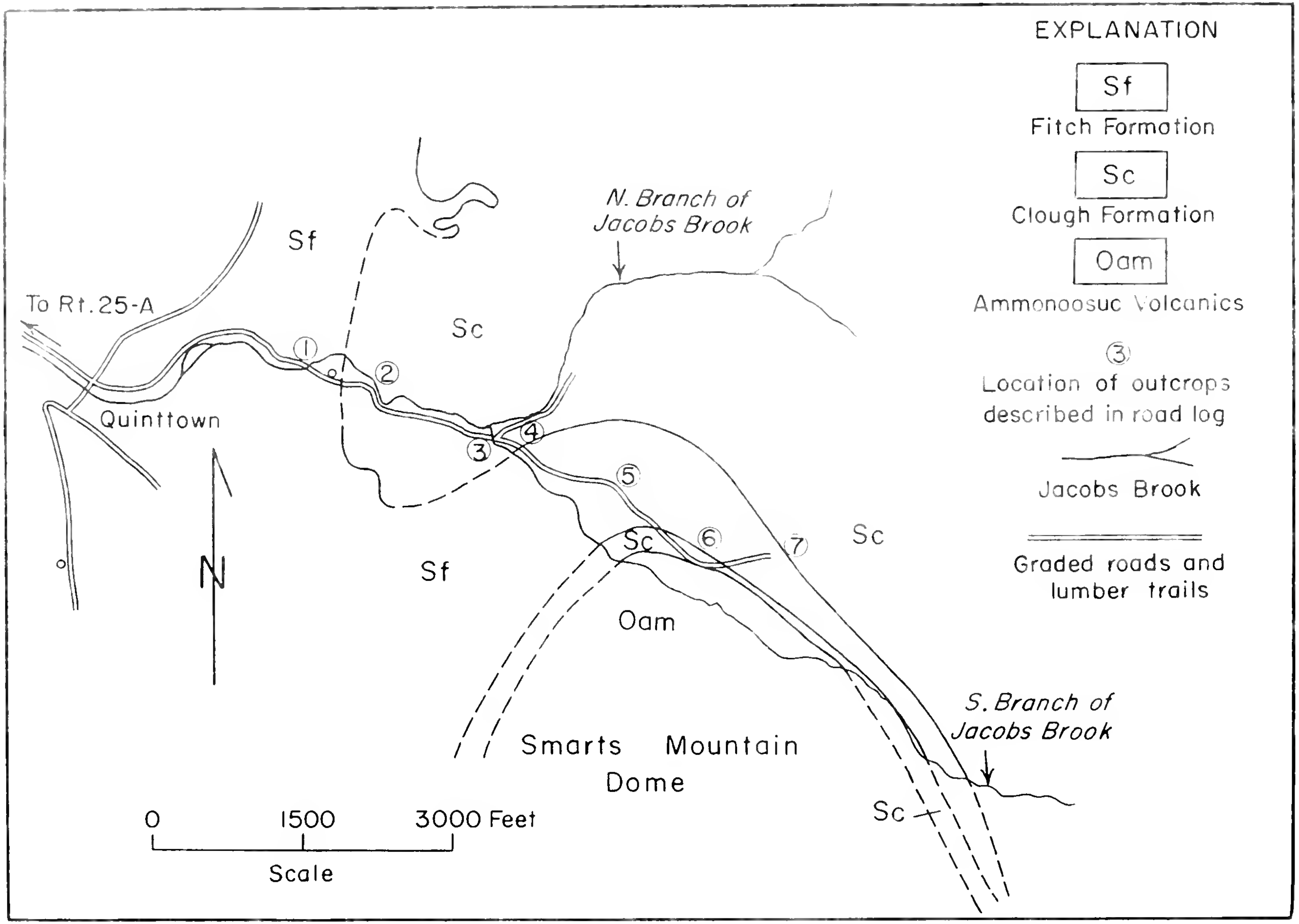

Figure 2 Geologic Map of the Jacobs Brook Recumbent Syncline

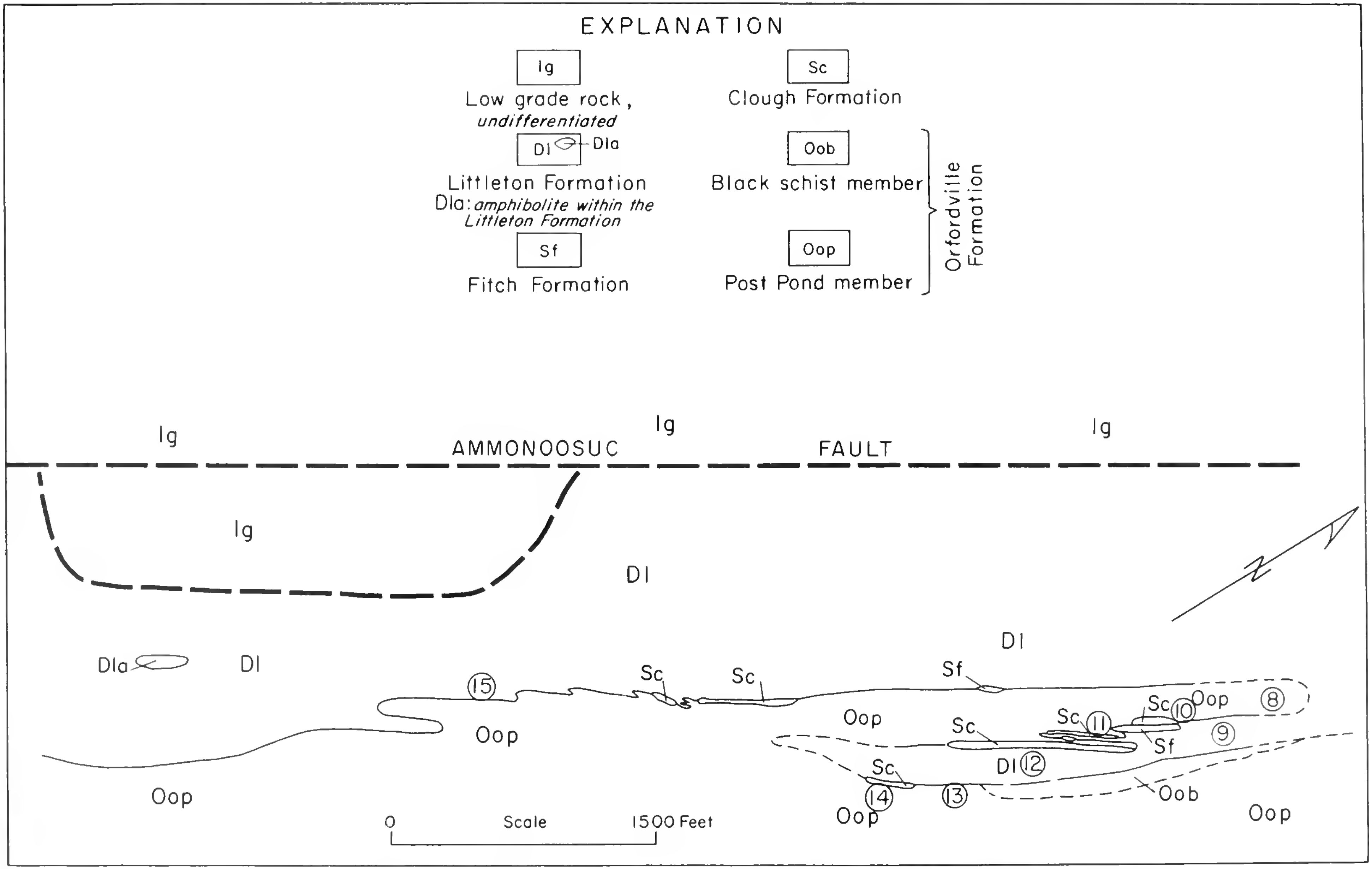

Figure 3 Geologic Map of the Wilmot Mountain Reclined Fold

ROAD LOG FOR TRIP A-6

From Concord proceed northerly on Interstate 23 for 41 miles to Plymouth, N. H. and the intersection of I-93 and Route 25. Road log commences where Route 25A turns left off Route 25.

Mileage

0.0 Rt. 25 exit west from I-93; proceed west on Rt. 25. Left turn onto Rt. 25-A towards Orford.

24.9 Left turn onto gravel road to Quinttown.

27.0 Bridge over Jacobs Brook.

STOP 1 Calcareous biotite schist of the Fitch Formation with upright, N-plunging folds in schistosity and concordant quartz veins. These rocks lie in the refolded inverted limb of the Jacobs Brook recumbent syncline.

27.2 Park cars and proceed E on lumber road (see Figure 2).

STOP 2 Quartzite, quartz-mica schist, and garnet-mica schist of the Clough Formation with upright folds in compositional layering and crinkle lineation in mica schist. Refolded inverted limb of Jacobs Brook recumbent syncline.

STOP 3 Beneath bridge over S fork of Jacobs Brook. Quartzite and quartz-mica schist of the Clough Formation; compositional layering and schistosity have uniform NE strike. Refolded inverted limb of recumbent syncline.

STOP 4 Quartzite and quartz-mica shist of the Clough Formation; compositional layering and schisosity strike uniformly E-W. Refolded inverted limb of recumbent syncline.

STOP 5

a) Outcrops near road: Actinolite-biotite schist, diopside-actinolite granulite, and hornblende amphibolite with feldspar porphyroblasts of the Fitch Formation. Compositional layering and schistosity strike uniformly E-W.

b) Outcrops 200 feet N of road: Biotite schist with interlayered coticule (fine-grained garnet granulite). The coticule layers record refolded folds: the older folds are isoclinal and have an axial surface schistosity; the younger folds are more open and are of reclined orientation. The anomalous orientation of the younger folds may be explained by supposing that the ductile rocks of the Fitch Formation lying in the core of the recumbent syncline flowed laterally to the west during the formation of the Smarts Mountain dome.

STOP 6 Quartzite of the Clough Formation overlain by actinolite-diopside granulite and fine-grained quartzite of the Fitch Formation. Hornblende amphibolite and quartz-feldspar-biotite gneiss of the Ammonoosuc Volcanics underlie the Clough and are exposed in lumber road 200' to E. Schistosity and compositional layering strike uniformly E-W. These rocks lie in the right-way-up limb of the recumbent syncline.

STOP 7 Diopside-actinolite granulite, biotite schist, actinolite-biotite schist, and marble of the Fitch Formation overlain by quartzite of the Clough Formation. There are isoclinal, reclined folds in the contact that are parasitic to the recumbent syncline. These rocks are exposed in the inverted limb of the recumbent syncline.

Return to cars.

Return to Rt. 25-A.

29.5 Left turn onto Rt. 25-A, toward Orford.

34.8 Right turn (N) onto combined Rts. 10 and 25-A.

35.2 Left turn across 25-A bridge to Fairlee.

35.4 Left turn (S) onto US 5.

Lunch stop on Fairlee town green.

Continue S on US 5 after lunch.

44.6 Right turn onto gravel road toward Stevens School.

(Cross I-91 on bridge.)

45.8 Left turn onto gravel road (first left past I-91).

50.0 Park cars. Gate and overgrown road on left lead up to Wilmot Mountain (see Figure 3).

Most of the Wilmot Mountain traverse will be across continuous outcrop. The stop locations and descriptions are intended to call attention to important rock types rather then to refer to specific rocks at specific locations.

STOP 8 Hornblende amphibolite of the Post Pond Volcanic member of the Orfordville Formation.

STOP 9 Quartz-muscovite-biotite-garnet-kyanite schist of the Littleton Formation.

STOP 10 Quartz conglomerate of the Clough Formation in contact, to the E, with calcareous quartz-muscovite-chlorite schist of the Fitch Formation.

STOP 11 Continue south along strike. Note the left-hand offsets in the Siluro-Devonian/Pre-Silurian contact. Hornblende amphibolite of the Post Pond Volcanics, to the W, in contact with quartz conglomerate of the Clough Formation. Calcareous quartz-muscovite-chlorite schist of the Fitch Formation and quartz-muscovite-biotite-garnet schist of the Littleton Formation in contact with Clough Formation to E.

STOP 12 Walk across strike to SE. Cross outcrops of quartz-muscovite-biotite-garnet-kyanite-staurolite schist of the Littleton Formation. Note quartz-kyanite veins.

STOP 13 Hornblende amphibolite and hornblende gneiss of the Post Pond Volcanics.

STOP 14 Quartz conglomerate of the Clough Formation in contact to E with hornblende amphibolite of the Post Pond Volcanics and in contact to W with quartz-muscovite-biotite-garnet schist of the Littleton Formation. Amphibolites with colorless amphiboles have been collected from the Post Pond Volcanics in this area.

Return to cars.

If time permits and the group so desires, an additional stop may be made at Stop 15 (Figure 3).

STOP 15 Exposure of the Siluro-Devonian/Pre-Silurian unconformity. The Pre-Silurian rocks are hornblende amphibolites and coticule (fine-grained garnet granulite) schists of the Post Pond Volcanics. The Siluro-Devonian rocks are the quartz-muscovite-biotite-garnet-staurolite-kyanite schists of the Littleton Formation with abundant quartz-kyanite veins. The unconformity has been folded into left-handed asymmetric folds of reclined orientation. The coticule schist records the asymmetric folds in spectacular fashion. Quartz conglomerate of the Clough Formation is found 200 yards to the north along the contact.

TRIP A-7

THE HILLSBORO PLUTONIC SERIES IN SOUTHEASTERN NEW HAMPSHIRE FIELD CRITERIA IN SUPPORT OF A PARTIAL MELTING PETROGENETIC MODEL

Daniel A. Sundeen
Chevron Oil Company
Western Division
Midland, Texas

Introduction

The Hillsboro Plutonic Series consists of a group of plutonic intrusive rocks that crop out in southeastern New Hampshire. The rocks in this series are listed below in their apparent chronological order based on intensity of deformation or foliation and their crosscutting relationships. The locations of the major intrusive bodies of the various rock types are shown in Figure 1.

Magmas of the Hillsboro Plutonic Series were intruded into the metasedimentary rocks of the Merrimack Group. The Merrimack is made up of schists, quartzites, phyllites and calc-silicate granulite rocks of the Kittery, Eliot, and Berwick formations, all of Silurian(?) age (Billings, 1956). The Littleton Formation (Devonian), although not part of the Merrimack Group, is also present to a limited extent in southeastern New Hampshire (Billings, 1956 and Sriramadas, 1966).

The Rockingham anticlinorium is the major structural feature in south-eastern New Hampshire. It lies between the Atlantic Ocean and the Fitchburg pluton (Billings, 1956) and is oriented northeast-southwest.

The chief purpose of this field trip is to demonstrate to the participants some of the field criteria that so strongly imply the granite-to-norite intrusive sequence. The partial melting of deep crustal material is used by the author to provide the mechanism for this intrusive sequence.

During the course of the trip several stops will be made to observe outcrops which exhibit other items of regional stratigraphic and structural interest. The phyllitic Calef member of the Eliot Formation, and the evolution of S_1, S_2, and S_3 planar structural elements are discussed in the road log.

Acknowledgments

The author spent two summers in southeastern New Hampshire doing field work for a doctoral dissertation. The major subjects of study were the petrology and geochemistry of the Haverhill 15' quadrangle. The work was done under the direction and assistance of Professors Vitaliano, Towell, and Hendrix of Indiana University and Professor Glenn Stewart of the University of New Hampshire. Institutional support was given by Indiana University and specific support was given through a Geological Society of America Penrose Bequest and by the State of New Hampshire Planning and Development Committee.

Petrography of the Hillsboro Plutonic Series

The brief descriptions given below were condensed from the detailed petrography of the rocks in the Haverhill 15' quadrangle (Sundeen, 1970).

Sweepstake norite (last of the series to be emplaced) - dark purplish-gray to black, coarse grained, massive norite. It is composed of labradorite, hypersthene and augite.

Island Pond diorite - mottled dark greenish-gray to black, coarse grained, massive diorite. It is composed of biotite, hornblende, actinolite, augite and andesine-labradorite.

Exeter diorite - mottled, dark greenish-gray, coarse grained, generally massive diorite. It is composed of biotite, hornblende,actinolite, oligoclase and quartz.

Sweepstake diorite - mottled light to dark greenish or purplish-gray, medium to coarse grained with both massive and foliated textures. It is composed of biotite, actinolite, andesine-labradorite and quartz.

Quartz monzonite - light gray to light brown, medium grained, massive to moderately foliated. It is composed of quartz, microcline, oligoclase, biotite and muscovite.

Ayer granodiorite - creamy to bluish-gray, coarse grained, slightly foliated quartz monzonite[1] with a porphyritic texture. It is composed of quartz, oligoclase-andesine, microcline, biotite and muscovite with microcline phenocrysts.

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[1] In the Haverhill quadrangle rocks which appear to be an extension of the Ayer Granodiorite series from the Manchester quadrangle differ in composition and dominant texture from the non-porphyritic granodiorite in the type locality in Ayer, Massachusetts (Jahns, 1962, p. 112).

Island Pond porphyritic quartz monzonite - light creamy gray to dark greenish-gray, foliated quartz monzonite, with a porphyritic texture. It is composed of quartz, microcline, oligoclase, and biotite with microcline phenocrysts.

Two-mica granite (first of series to be emplaced) - light gray to light brown, medium to coarse grained, massive to intensely foliated, composed of quartz, microcline, oligoclase, biotite and muscovite with microcline phenocrysts common in the foliated granite.

Petrology and Geochemistry

Questions regarding the "where" and "what" of rocks in the Hillsboro Pultonic Series have been answered by field work and thin section petrography. A two dimensional picture has been developed as a regional geologic map. But before the third dimension (depth) and a fourth dimension (time) can be added, a fuller understanding is necessary of the details of "how" these magmas were generated and the evolution of these magmas prior to emplacement.

It is important to know whether these plutons in southeastern New Hampshire are either rooted in a major batholith a few thousand feet below the surface or represent ends of "straight-pipes" to a former hot spot at the crust-mantle interface. Models for gravity and magnetic data would differ significantly from one petrogenetic model to another.

On this field trip evidence for the sequence of intrusion (granite to norite) will be examined. Figure 1 in the guidebook shows the distribution and relative abundance of the various rock types. In addition to the field data, standard chemical (10) and trace element (12) analyses were determined for selected rock samples.

Major Element Oxides

The results of the analyses plotted on AFM and CaNaK variation diagrams are similar to results of other complex igneous provinces such as the Batholith of Southern California (Nockolds and Allen, 1954). The smooth lines in the variation diagram of the Southern California Batholith are believed to represent a line of evolution of related magmatic liquids. Phases stable under high temperature and pressure conditions consist of relatively higher percentages of Fe, Mg, and Ca than those phases

stable under lower energy conditions. Labradorite, hypersthene, and augite would be expected to crystallize first, settle out and leave a residual melt enriched in K, Na, and SiO_2. The residual melt of granitic composition would be one of the last to be emplaced.

Does the similarity of variation diagrams constructed from data from the Hillsboro Plutonic Series and from the Southern California Batholith require that their petrogenesis likewise be similar? Fractional crystallization with successively more silicic residual melts seems to be a reasonable interpretation for the igneous history of the area studied by Nockolds and Allen.

What about southeastern New Hampshire where magmas of granitic composition were intruded before those magmas of a dioritic or noritic composition? It is reasonable to expect that successive magmas generated from the partial melting of crustal rock would have compositions that would plot as a smooth continuous curve on a variation diagram. Those mineral phases which were the last to form from residual magmas during cooling in a fractional crystallization process would be the first to become magmas as temperatures increased during a partial melting process of crustal material. The first melts would be rich in Na, K, and SiO_2 and the desilicified crustal material would become richer in Fe, Mg, and Ca. The composition of the melts produced from desilicified residual crust would become increasingly more mafic as temperatures increased.

Although variation diagrams of plutonic series with differing petrogenetic histories may show remarkably similar curves, the direction in which the line progresses (based on the chronological order of the magmas produced) is reversed.

Trace Elements

Rare earth concentrations were determined for eight elements (La, Ce, Pr, Nd, Sm, Gd, Dy, and Y) for selected samples of the Hillsboro Plutonic Series. Results showed that 1) the total concentration of all rare earths was greatest in granite and quartz monzonite and 2) the relative abundance of the light rare earths (La, Ce, Pr, Nd) to the heavy rare earths (Gd, Dy and Y) was also greatest in granites, quartz monzonites, and quartz diorites. These abundance trends are easily explained (Ringwood, 1955) and are compatible with both fractional crystallization and partial melting models.

Rb, Sr, and K concentrations were determined and Rb/Sr and K/Rb were plotted against (1/3 SiO_2 + K_2O - CaO - MgO - FeO). Wide scatter in these ratios made it impossible to define a constant trend.

Conclusion

Geochemical studies to date exhibit trends which can be explained by both fractional crystallization and partial melting petrogenetic models.

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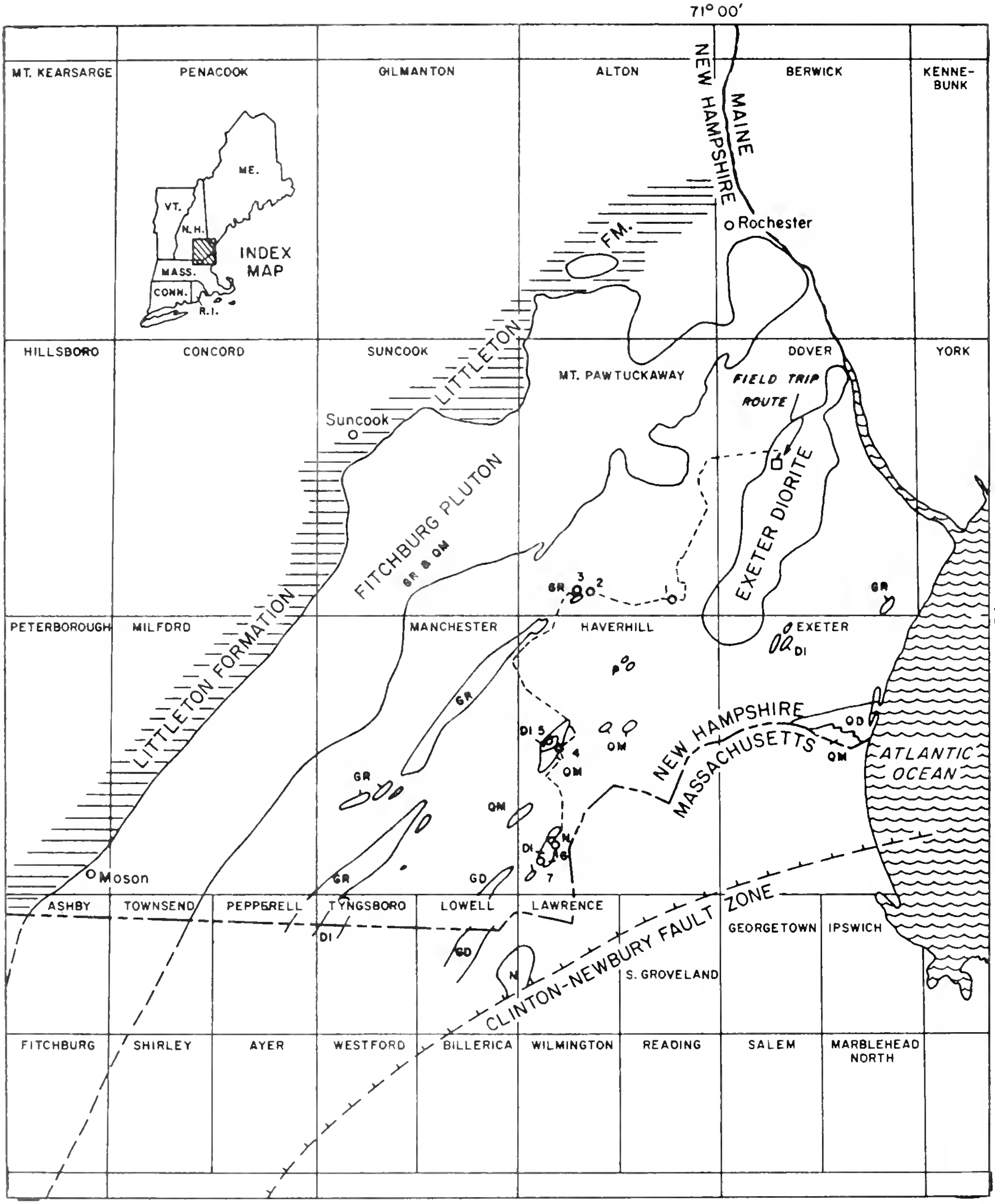

FIGURE 1. LOCATION OF THE MAJOR INTRUSIVE BODIES OF THE VARIOUS ROCK TYPES IN THE HILLSBORO PLUTONIC SERIES, SOUTHEASTERN NEW HAMPSHIRE.

(GR = GRANITE; QM = QUARTZ MONZONITE; GD = GRANODIORITE; QD = QUARTZ DIORITE; DI = DIORITE; N = NORITE; P = PEGMATITE)

ROAD LOG FOR TRIP A-7

Proceed easterly from Concord on Route 4 for 34 miles to the campus of the University of New Hampshire at Durham, where a brief stop is made near the Student Union Building to examine several outcrops of the Exeter Diorite. The path from the parking lot to the old library hall is paved with Exeter Diorite stepping stones. A "heads-down" walk along this path will give a quick demonstration of the variety of colors and textures present locally in the Exeter Diorite. A thin, white aplite dike may be seen in a small outcrop(?) of Exeter Diorite on the College Brook path between the Union and the library. Begin road log.

Mileage

0.0 Turn right (east) upon exiting from the parking lot and proceed to Madbury Road.

0.3 Madbury Road at the U. S. Post Office Building. Turn left (north) onto Madbury Road and proceed to Route 4.

0.65 Junction Route 4. Proceed west on Route 4. The large outcrops are Exeter Diorite. Notice the complex joint system.

4.45 Fresh outcrops at Lee Five Corners (Route 155) are schists of the Eliot Formation.

5.95 Junction Route 125. Proceed south on Route 125.

6.95 Wheelright Pond on left.

7.00 Schists and granulites of Berwick Formation on right.

10.05 Intersection Route 152. Continue south on Route 125. This road is locally known as the Calef Highway and it follows the old railroad bed of the Boston and Maine Railroad.

11.35 Intersection Route 155. Outcrops are composed of a phyllitic member of the Eliot Formation.

13.15 Turn right (west) onto small tarred road (this road leads to Hedding Campground if a left (east) turn were made off of Route 125).

13.40 Bear left at fork in road.

13.55 Outcrops along the road are typical of the Calef member of the Eliot Formation. The Calef is composed of a pyritiferous, carbonaceous phyllite and is a distinctly different facies of the calcareous Eliot Formation. It crops out along the Calef Highway in a band less than a mile wide striking NNE-SSW and has been traced for about eight miles (Freedman, 1950). This same type of phyllitic rock occurs along the eastern flank of the Rockingham anticlinorium.

This occurrence also is less than a mile wide and has been traced along a NNE-SSW trend for about seven miles (Billings, 1956; Sundeen, 1970). Several thoughts about the Calef come to mind, teasing the imagination. Could this phyllite be used as a lithologic-stratigraphic marker within the otherwise monotonously consistent Eliot Formation? And, could the Calef and similar phyllites in southeastern New Hampshire correlate with phyllites in the Worcester Formation (Pennsylvanian) in northeastern-central Massachusetts? A recent paper about this area (Grew, 1970) describes a phyllitic facies in the Oakdale Formation (Silurian) which has been correlated with the Merrimack Group. Grew indicates that in the Worcester area, the phyllite represents a lower metamorphic facies of the Oakdale. In southeastern New Hampshire, the Calef is a different sedimentary facies within the Eliot. And so the battle goes on . . .

14.65 Junction with Main Street of Epping. Turn left (south).

15.20 Bridge over Lamprey River.

15.30 Old Route 101. Turn left (east).

15.55 Junction Route 125. Turn right (south) at traffic lights.

15.85 Boston and Maine Railroad. To the southeast are the clay pits for the Goodrich Brick Company.

16.25 Intersection Route 101. Turn right (west).

16.55 STOP 1 Boston and Maine Railroad. At this stop the characteristics of the Calef member and its occurrence in the Eliot Formation will be studied. This occurrence and one other about one mile to the south extend the Calef member an additional three miles south along strike from the area designated by Freedman (1950). Both schists and phyllites are present in these relatively fresh outcrops on the north side of the road. Notice the crenulations (minor folds) in the phyllite. There are two sets of minor folds of the same size and their fold axes describe a plane parallel to the bedding plane. Other lithologic units present are porphyroblastic (biotite) schists, and quartz-biotite schists. Proceed west on Route 101.

19.05 STOP 2 The large outcrops on the left (south) side of Route 101 are schists and granulites of the Eliot Formation. The purpose of this stop is to observe and discuss the planar structural features of these metamorphic rocks.

Along the outcrop from west to east are examples of compositional bands that probably represent original bedding (S_1). In these beds are mica (biotite) flakes oriented parallel to the bedding plane, a foliation subsequent to deposition caused by metamorphism (S_2). Both S_1 and S_2 have been slightly folded at the western edge of the outcrop. At the eastern edge of the outcrop, the folds have become isoclinal, slip cleavage has occurred parallel to the fold axial planes, and the foliation due to orientation of micaceous minerals is now parallel to the axial plane,

not the bedding plane, and is designated S_3. Proceed west on Route 101.

19.65 STOP 3 The rock in the outcrop at this stop is two-mica granite. This granite exhibits schlieren, foliation, and elongated clusters of minerals. These textural features are the result of tectonism synchronous with the emplacement of granitic magma. (If time permits, an additional stop will be made at the next outcrop about 0.2 miles further west on Route 101.)

The dikes intruding the Eliot Formation are rhyolitic(?) and andesitic(?) in composition. They belong to the White Mountain plutonic-volcanic series of Jurassic age (Freedman 1950, Billings, 1956). These dikes are probably associated with the Little Rattlesnake Hills volcanic complex located about three miles to the southwest and with the Pawtuckaway Mountain ring dike about six miles to the northwest (Freedman, 1950).

20.00 Lamprey River

20.85 Junction with To Routes 102, 107, and 101. Bear left (south) and follow signs to Route 102 and Chester.

22.05 Junction Routes 102 and 107. Bear right (southwest) and follow Route 102.

23.40 Little Rattlesnake Hills on right (west).

24.60 Entering town of Chester. Route 102 is roughly parallel to the contact of the Berwick and Eliot formations.

26.40 Lane Road to right (northwest) leads to another area where the two-mica granite crops out extensively. The granite is cut by a diabase dike about sixty feet wide, striking generally north-south and dipping steeply to the west (Sundeen, 1970). Continue south on Route 102.

28.80 Center of Chester and junction with Route 121. Turn left (east) on Route 121.

28.95 Junction Route 121-A, bear right and continue on Route 121 to Hampstead.

32.05 Television relay tower on Walnut Hill. For the last two miles the schists and granulites seen in outcrops belong to the Eliot Formation. This part of the Haverhill quadrangle is intruded by numerous small granite, quartz monzonite, or pegmatite bodies that generally are concordant with the foliation of the host rock.

35.55 Tel Noar Youth Camp. This area marks the northermost edge of the Island Pond porphyritic quartz monzonite.

36.35 Center of Hampstead. Turn right (west).

37.05 Sharp left turn in road. Private road to Governors Island on right.

37.15 STOP 4 Dirt road on left, pull in and park automobiles. On the west side of the road is a relatively fresh outcrop of the Island Pond porphyritic quartz monzonite. Notice the strongly deformed texture. There is also a distinct banding due to relative amounts of biotite and feldspars. This outcrop is representative of the mineralogy and texture of the Island Pond porphyritic quartz monzonite.

At this point, it would be best to consolidate the group into as few cars as possible. We will backtrack and follow the road to Governors Island.

37.55 STOP 5 A small inlet nearly reaches the left (south) side of the road. On the north side of the road are large boulders and cliffs. These are made up of the Island Pond diorite. Notice the contrast in textural properties, namely, a massive texture. Mapping of the area (Sundeen, 1970) shows the massive diorite is surrounded by the foliated porphyritic quartz monzonite.

The sequence of intrusion of the Island Pond plutonic rocks as suggested by field observation is: 1) porphyritic quartz diorite, synchronous with late stages of tectonism and then 2) massive diorite.

Return to cars parked at STOP 4 and proceed south to join Route 111.

38.70 Junction Route 111. Turn right (west) onto Route 111. Outcrops along the next several miles are schists of the Eliot Formation and quartz monzonite.

39.70 Salem town line.

39.95 Road cuts back to left (southeast). Make this sharp turn to the left. Poorly exposed outcrops of porphyritic quartz monzonite are exposed on the south side of the road and they are close to the southern limit of this plutonic body. Proceed past the Mystery Hill area.

41.30 Main Street. Turn right (south) and continue into Salem Center.

41.65 Fork in road. Continue straight ahead (left fork).

44.30 STOP 6 Pine Grove Cemetery. Park automobiles on the old side road at the southern entrance to the cemetery. This will be a short stop to gain a quick glimpse of the variety of rock types present in the Sweepstake diorite pluton. The cemetery is underlain by diorite and norite. The stone wall was built of stone quarried locally and (as did the sidewalk near the Student Union) it displays an interesting variety of rock colors, textures and eccentricities. In general the more deformed textures are indicative of quartz diorites, the more massive textures are indicative of diorite and norite. Proceed south and immediately join Route 97.

44.35 Route 97. Turn right.

44.65 Cross School Street. Continue southwest on Main Street.

44.75 Turn left (south) onto next street.

45.45 Turn right (west) onto Veterans Memorial Parkway.

45.65 STOP 7 Intersection of Veterans Memorial Parkway and Ceremonty Drive. This outcrop exhibits a variety of igneous intrusive phenomena. A full description is in the literature (Sundeen, 1970). A list of items of interest is given below in the probable geologic order of occurrence:

Slightly foliated quartz diorite (biotite-chlorite mafics)
Biotite schist-xenoliths from the Eliot formation
Massive diorite (actinolite-diopside mafics)
Amphibole-rich contact zone between early and late diorites
Zoned pegmatite dikes displaying graphic textures and garnet-tourmaline-apatite aplitic cores
Gossan; remnant of a joint-oriented sulfide vein.

The preservation of schistose xenoliths and the foliation of the quartz diorite (parallel to the regional foliation in the metasedimentary rock) sets limits on the age of intrusion of the Sweepstake quartz diorite. It can be no older than regional metamorphism (Late Devonian) and can be no younger than the end of the Acadian Orogeny (Late Devonian; possibly a last pulse in very Early Mississippian). The diorites and norites are younger than the quartz diorite (a conclusion based on their having massive textures), and therefore were intruded after the last tectonic pulse.

Veterans Memorial Parkway continues west passing south of Rockingham Park. This race track has the unique distinction of being the only one in the country that regularly runs sweepstakes to supplement state funds for public education. Just west of the park is the entry ramp to Interstate 93.

End of Trip.

TRIP A-8

BEDROCK GEOLOGY OF THE OSSIPEE LAKE AREA

J. Robert Wilson
Phillips Academy
Andover, Massachusetts

Introduction

This trip will study some igneous and metamorphic rocks on the southeastern edge of the White Mountain batholith and in the Ossipee Mountains ring dike complex. The oldest rocks are sillimanite-mica schists of the Littleton formation (Early Devonian). These schists are intruded by gray, medium-grained, two-mica calc-alkaline granitic rocks of the New Hampshire Plutonic Series (Middle Devonian) and by pegmatite. The pegmatite is somewhat younger than the granitic rocks of the New Hampshire Series. There are also volcanic rocks (rhyolite, andesite, basalt and breccia) and coarse-grained to porphyritic, pink and green hypersolvus granites and porphyritic quartz syenite of the White Mountain Plutonic-Volcanic Series (Early Jurassic). Quarternary glacial deposits (sand plains, reworked stream deposits, a couple of eskers) cover most low-lying parts of the area. There will be ample opportunity to collect hand specimens. This area has been mapped at 1:62,500 by Wilson (1969). For a regional setting refer to Billings (1956) and Doyle (1967).

Littleton Formation

The Littleton Formation crops out in a broad belt across the center of the area and is always intimately associated with pegmatite and granitic rocks of the New Hampshire Plutonic Series. This formation contains pelitic schist (sillimanite-almandite-plagioclase-muscovite-biotite-quartz with tourmaline in places), granofels (plagioclase-mica-quartz with minor almandite), calc-silicate granofels (sphene-actinolite-quartz-biotite-labradorite) and migmatite gneiss. The sillimanite is fibrolitic and commonly is intimately associated with biotite to give the mica a matted appearance in thin section. The pelitic schist was apparently

not aluminous enough to have produced andalusite or kyanite prior to sillimanite. Judging from experimentally determined stability relations, the sillimanite can be interpreted as a superimposed high temperature product of intense and extensive plutonic intrusion between roughly 4 to 7 kb (about 15 to 27 km of rock of S. G. 2.75) and between roughly 650 and 700°C. For discussions on the regional distribution of the Al_2SiO_5 polymorphs see Albee (1968) and Thompson and Norton (1968), in E-an Zen, Studies of Appalachian Geology: Northern and Maritime: John Wiley and Sons, Inc., Interscience, N. Y.

The structure of the Littleton Formation in this area remains indistinct due to the glacial cover and extensive outcrops of pegmatite and plutonic rocks of the New Hampshire series. The schistosity is consistently parallel to the bedding, which consists of alternating beds of schist and granofels a few cm. thick. The bedding-schistosity generally strikes in a northeasterly direction. There are lineations due to crinkle axes that plunge to the southwest. Top/bottom criteria are extremely rare (some graded bedding). Assuming congruous drag folds, the structure in the eastern part of the area appears to be situated on the southeast limb of a syncline plunging to the southwest.

The Littleton Formation can be continuously traced from the Littleton-Moosilauke district into this area (Billings, 1955). The fossil studies in and near that district confirm the age of the Littleton Formation to be Lower Devonian in the type locality (Billings and Cleaves, 1934; Boucot and Arndt, 1960). The Silurian rocks in Southwestern Maine, the Eliot and Berwick Formations (Doyle et al., 1967), have been correlated with the fossil bearing slates of the Waterville, Maine district (Osberg, 1968) lying 90 miles to the northeast. Hussey has mapped the structure in these Silurian rocks and has shown the stratigraphy to proceed up-section towards the northwest from the south edge of the Sebago batholith. The Kezar Falls and Newfield areas mapped by Gilman form a link between the Silurian rocks to the southeast and this area. Thus the rocks assigned to the Littleton Formation in this area can be traced to the northwest and east into strata that overlie Silurian formations and are considered to be Lower Devonian.

New Hampshire Plutonic Series

WINNIPESAUKEE QUARTZ DIORITE

In this area the Winnipesaukee quartz diorite is restricted to the Ossipee Mountains. This rock is light gray, medium-grained, equigranular and composed of quartz, sodic andesine, orthoclase, biotite and muscovite. This rock locally exhibits a mylonitic texture suggestive of faulting or crushing.

TRONDHJEMITE

In the northeast portion of this area the most common granitic rock, other than pegmatite, is trondhjemite, a light-gray, fine-grained, equigranular rock composed of quartz (30%), plagioclase (An_{29}, 45%), orthoclase (8%), biotite (16%), and muscovite (1%), with a trace of monazite.

QUARTZ MONZONITE

There is one small stock of quartz monzonite. It is entirely surrounded by Conway granite in the north-central part of the area. This rock is light-gray, medium- to coarse-grained and subporphyritic. It contains traces of sillimanite.

CONCORD GRANITE

This rock is fairly common throughout the central portion of the area. It is light-gray, medium-grained, equigranular and contains traces of almandite and sillimanite locally. This rock grades into quartz monzonite in places. The name is equivalent to binary granite, but is intended to specifically imply the youngest granite of the New Hampshire Plutonic Series.

Pegmatite

Pegmatite is extremely common throughout the central part of the area.

White Mountain Plutonic-Volcanic Series

MOAT VOLCANICS

The Moat Volcanics consist primarily of porphyritic rhyolite, porphyritic basalt, basalt and basaltic breccia. Some andesitic tuff and welded tuff is also present. Besides flows,

there are several places where the volcanics appear to be the remnants of shallow pipes or plugs. L. R. Page has observed what he considers to be the dip slopes of cone sheets on the west side of the Ossipee Mountains. In places it is at first questionable whether one is observing the Albany Porphyritic Quartz Syenite or a variety of shallow intrusive volcanics.

ALBANY PORPHYRITIC QUARTZ SYENITE

This rock contains microperthite (60%), anorthoclase (10%), quartz (20%), hastingsite (10%) with minor biotite, augite, magnetite, zircon, fayalite and apatite. The hastingsite is poikilitic. Some of the anorthoclase is mantled with rims of of K-spar. Some hastingsite occurs as a reaction rim around small augite grains.

MT. OSCEOLA GRANITE

This rock is a coarse-grained, equigranular, olive-green to gray granite. It is about 75% microperthite, 20% quartz with 1 to 8% hastingsite, plus minor hedenbergite, fayalite, fluorite, apatite, albite and zircon.

CONWAY GRANITE

The Conway granite has been dated by various workers using samples collected in the Redstone Quarry. The generally accepted age is 185 m.y.

This rock is typically a medium- to coarse-grained, light pink to buff colored, equigranular biotite granite. The biotite is extremely iron-rich. Fluorite, magnetite, fayalite, zircon, allanite, rutile, apatite and molybdenite are also present. The Redstone quarry has also been the source of well crystallized miarolitic cavities in the Conway granite containing large, euhedral crystals of quartz and microcline-perthite.

DIKE ROCKS

The most common dike rock in this area is camptonite. Two large camptonite dikes occur, both containing euhedral barkevikite. Spessartite and felsite dikes also are present, along with the usual diabase.

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Topographic maps needed: Ossipee Lake, North Conway U.S.G.S. 15-minute topographic sheets

GEOLOGIC MAP of the OSSIPEE LAKE AREA
(modified from Wilson, 1965)

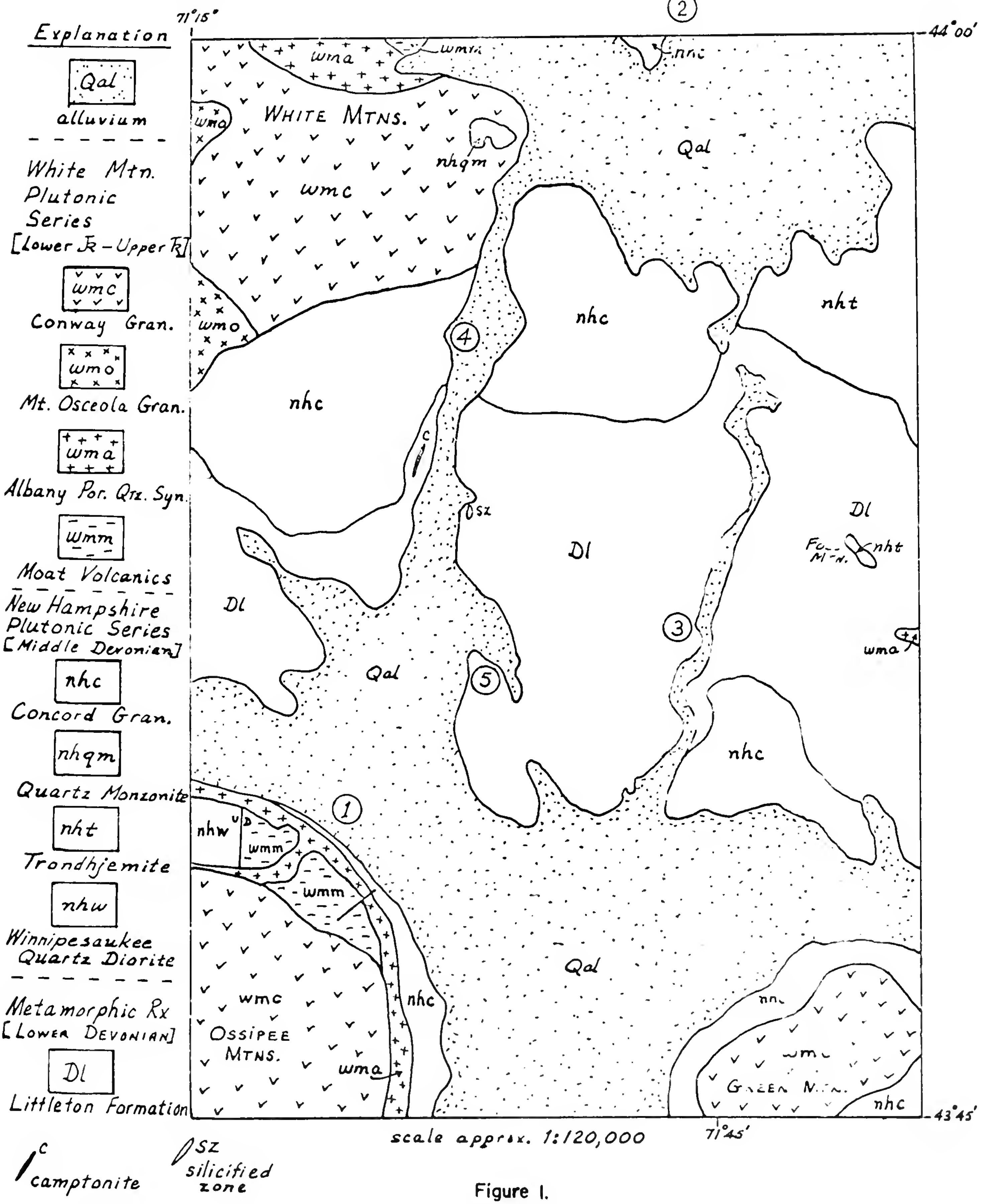

Figure 1.

ROAD LOG FOR TRIP A-8

Take Interstate 93 north for 30 miles to its intersection with Route 104. Follow 104 for 9 miles easterly to Route 3. Turn left (northerly) for 1 mile to Meredith, and turn right on Route 25. Continue on Route 25 through Moultonboro for 24 miles to Route 16 and the Mt. Whittier ski gondola parking lot. Cost of ride is $2.00. Road log begins here, with a gondola ride.

Mileage

0.0 STOP 1 Moat Volcanics and Albany Porphyritic Quartz Syenite The Albany is pink weathering with abundant feldspar crystals (some zoned), not much quartz and a minutely peppered groundmass due to hastingsite. The Moat Volcanics here are chiefly porphyritic rhyolites. Some breccia and basaltic rocks are found a few hundred yards south and southeast of the top. The Albany is coarser grained than the Moat, but does occur as a chilled phase in some places. The contact is most clearly found about 40 yds. southwest of the unloading station. Here and there you might find a piece of Moat in the Albany. Some petrographers might prefer to call the Moat here rhyolite porphyry. Evidence for bedding in the volcanics here is absent. One question that almost immediately comes to mind is whether or not much of the Moat here consists of shallow intrusive rock.

Return to the bottom and proceed north on Rt. 16.

16.0 Pass through main intersection in Conway. Continue one block, then turn left to stay on Rt. 16 headed north.

18.9 Turn right on to Rt. 302.

19.6 Turn left on to dirt road across from Pines Motel.

20.1 Bear left near end of dirt road and park in vicinity of Mr. Fletcher's ski house. He owns much of the Redstone quarries. Mr. Harry Mason, a local resident, is caretaker. Walk through woods to base of the block slide.

20.2 STOP 2 Conway granite. The Conway granite is beautifully exposed here. The Redstone quarries have not been in commercial operation since 1942. In dating the Conway granite by various radiometric methods the several authors (Tilton, Aldrich, Hurley, et al.) all took their samples from this area. Various authors have also taken specimens from these quarries for chemical analysis (Billings, Henderson, Frye). The study by J. K. Frye (1965) is the most recent and thoroughly detailed one I know of.

The Conway granite, including its various forms, comprises between 50% and 60% of the total outcrop area in each of the four major areas in New Hampshire containing rocks of the White Mountain series. From the compositions of coexisting minerals in the miarolitic cavities found here, it is theoretically possible to estimate the conditions of pressure and temperature under which the granite

crystallized. To do this, however, certain assumptions are necessary concerning the aqueous phase, the most necessary one being that there was one. The cavities themselves supply this evidence, but they tend to occur in the planes in the granite, perhaps controlled by fissures. If so, even granting equilibrium, the P-T conditions inferred from the mineralogy in the cavities may not accurately reflect the conditions under which the granite mass as a whole crystallized.

We will plan to eat our lunch on the quarry site. Afterwards, proceed exactly in reverse along the route taken to the quarries as far as Conway.

24.4 Turn left (south) at main intersection in Conway.

24.7 Bear left at fork.

27.1 Cross intersection 558, heading south.

29.6 Arrive at head of Crystal Lake; bear right to Eaton Center.

30.1 Turn left in Eaton Center; head south.

33.1 Pass King Pine Ski Area.

34.2 STOP 3 Littleton Formation with pegmatite. Park in vicinity of Purity Lake Resort. We will take a trail west up a ridge towards Bald Ledge. The Littleton Formation weathers brownish and rusty here and is well bedded locally. Pegmatite is common. Granite rocks of the New Hampshire series also crop out here and there.

On returning to cars, head north.

34.4 Turn left, heading west.

36.6 Turn right, heading north, on Rt. 113.

38.1 Pass through Madison, heading north.

40.2 Turn left at sign advertising Madison Boulder.

40.8 Cross railroad tracks, stay right, on main dirt road.

41.4 STOP 4 Madison Boulder. The Madison Boulder is a gigantic glacial erratic which measures 83 x 37 x 23 feet and weighs about 4,662 tons. It is composed of Conway granite and is believed to have been plucked from Whitton Ledge (or perhaps even White Ledge?) to the northwest. Concord granite crops out on the ledges a couple of hundred yards to the west.

Proceed back to the main asphalt road (Rt. 113) and turn right, heading south.

44.7 Pass through Madison, heading south on Rt. 113.

47.9 Turn right, on to Lead Mine Road, heading west.

48.6 STOP 5 Madison Lead Mine. The Madison Lead Mine was last worked in the early twenties. The dominant sulfide minerals are galena and sphalerite deposited in a large silicified zone that trends north-south. Smaller silicified zones similar to this one are found all over New Hampshire and are taken as evidence for faulting, followed by mineralization. The main shaft, now water filled, lies just south of the dirt road; tailings lie north of the dirt road and extend to the south shore of Cooks Pond.

Proceed to Rt. 16 by continuing on this dirt road, around the southern tip of Silver Lake, for 1.8 miles, then turn left and proceed south on an asphalt road for 2.2 miles to West Ossipee where you will intersect Rt. 16.

If time and/or interest dictate, there are a couple of optional stops we could make in order to see more of a slightly different variety of the Albany or gneisses in the Littleton Formation.

TRIP B-1

JACKSON ESTUARINE LABORATORY; SEDIMENTATION IN GREAT BAY ESTUARINE SYSTEM; SOLID WASTE DISPOSAL IN GULF OF MAINE

Franz E. Anderson and Herbert Tischler
University of New Hampshire
Durham, New Hampshire

I. Jackson Estuarine Laboratory

A major marine science facility of the University of New Hampshire, the Jackson Estuarine Laboratory was constructed in 1969-1970 with grants from the National Science Foundation, the New England Regional Commission and with University appropriations. The location of the laboratory at Adam's Point affords easy access to the Great Bay estuarine system and to the Atlantic continental shelf.

Within 9000 square feet of space the Jackson Laboratory provides several individual research modules, an administrative wing and a variety of specialized facilities which include seawater trays, constant temperature rooms and a dark room. The University's 45 foot research vessel, R/V Jere Chase, moored at the laboratory, is also available to the marine scientists.

Faculty members and their students from the Departments of Biochemistry, Botany, Microbiology, Earth Sciences and Zoology are broughttogether in the Jackson Estuarine Laboratory where they often combine studies in biological, physical and geological oceanography. Many of the projects requiring instrument or structure design are carried out with the cooperation of the Ocean Engineering Group from the College of Technology.

II. Sedimentation in the Great Bay Estuarine System

Present Deposition:

Sedimentalogical studies of the Great Bay estuarine system have shown that coarse grained sands and gravels floor the channels of the main estuary, while silts and clayey silts comprise the bulk of the sediments found in the shallow tidal flat areas.

Most of the coarse grained sediments were cut off from the estuary early in the 19th century when numerous mills and dams were built on each river emptying into the bay (Exeter-

Squamscott River, Newmarket-Lamprey River, Durham-Oyster River, Dover-Bellamy, and Cocheco Rivers, Berwick-Salmon Falls River).

Because the finer grained suspended sediments are still being transported into the estuary especially during spring thaws and late fall rains, the Department of Earth Sciences at the University of New Hampshire has concentrated its sedimentological studies on the suspended matter in the estuarine waters. At the present time we have been examining the factors that change the daily and seasonal concentrations of suspended sediment. Data are being collected on the effect of resuspension by botton currents, resuspension by wind waves, local productivity, effects of ice, discharge, etc. In addition, proposed wave tank modeling should help isolate individual factors for more quantitative results.

Past Deposition:

In the recent geologic past the Great Bay estuarine system has been strongly modified by glacial conditions. Cores which we will attempt to obtain off of Thomas Point have shown the present channel is cutting into a probable "lake" deposit of varved sediments. At the present time the stratigraphy of the varved deposit and the overlying sediments is being reassembled by detailed coring up the channel walls.

III. Physical and Biological Implications of Solid Waste Disposal in the Continental Shelf Basins of the Gulf of Maine

"Solid wastes, the by-products and discards of our society, amounts to approximately 5.5 lbs. per capita per day collected by municipal and private agencies." This statement by the Council on Environmental Quality (October, 1970) translated into terms which relate to the Boston metropolitan area means an output of solid waste of about 6 million tons per year. Until recently solid waste was readily disposed of in nearby land-fill sites and in coastal areas or wet lands. Having been recognized as a serious detriment to our environment, the destruction of wet lands by this process has been curtailed; also land-fill tracts suitable for solid waste disposal have become exceedingly difficult to find. Although only a relatively small amount of solid waste is currently being disposed of in the oceans, there are strong indications that greater and greater use will be made

of the deeper marine realm as a receptor of the waste products of our large, coastal, metropolitan centers.

Off the New England coast, 100 to 150 km. east of Boston, several basins appear to be areas which are likely to be proposed as receptacles of urban wastes. These basins with a perimeter of several hundred km. and with a depth of greater than 200 meters could receive Boston's waste for many years. The question we are trying to answer in this project is: What effect will disposal of waste into these basins have upon the marine environment? We are coordinating our study of Jeffery's Basin, with similar investigations of the Murray and Wilkinson Basins by oceanographers at Woods Hole Oceanographic Institution.

The objectives of the study are to gain knowledge of:

a) the basin flushing rates in order to estimate the rate at which oxygen enriched water will flow through the basin.

b) the sedimentation rate in order to estimate the burying time of the solid waste.

c) the types of organisms presently occupying the basin and the effect upon them of changing the food source and substrate.

d) the physical properties of baled solid waste, the way in which the waste bales will behave in the basin environment, along with the engineering methodology required to observe, sample and return the bales during testing.

IV. Procedure for Trip B-1

This excursion is offered on Saturday, October 2 and Sunday, October 3. Because of space limitations the total number of participants on each day is limited to 15 persons, the order of priority being established by the order of receipt of paid-up registrations for NEIGC '71.

After a brief tour through the laboratory, the trip will proceed on a cruise and brief coring operation on Great Bay. At this time we can discuss the two studies which are described in Sections II and III of the write-up.

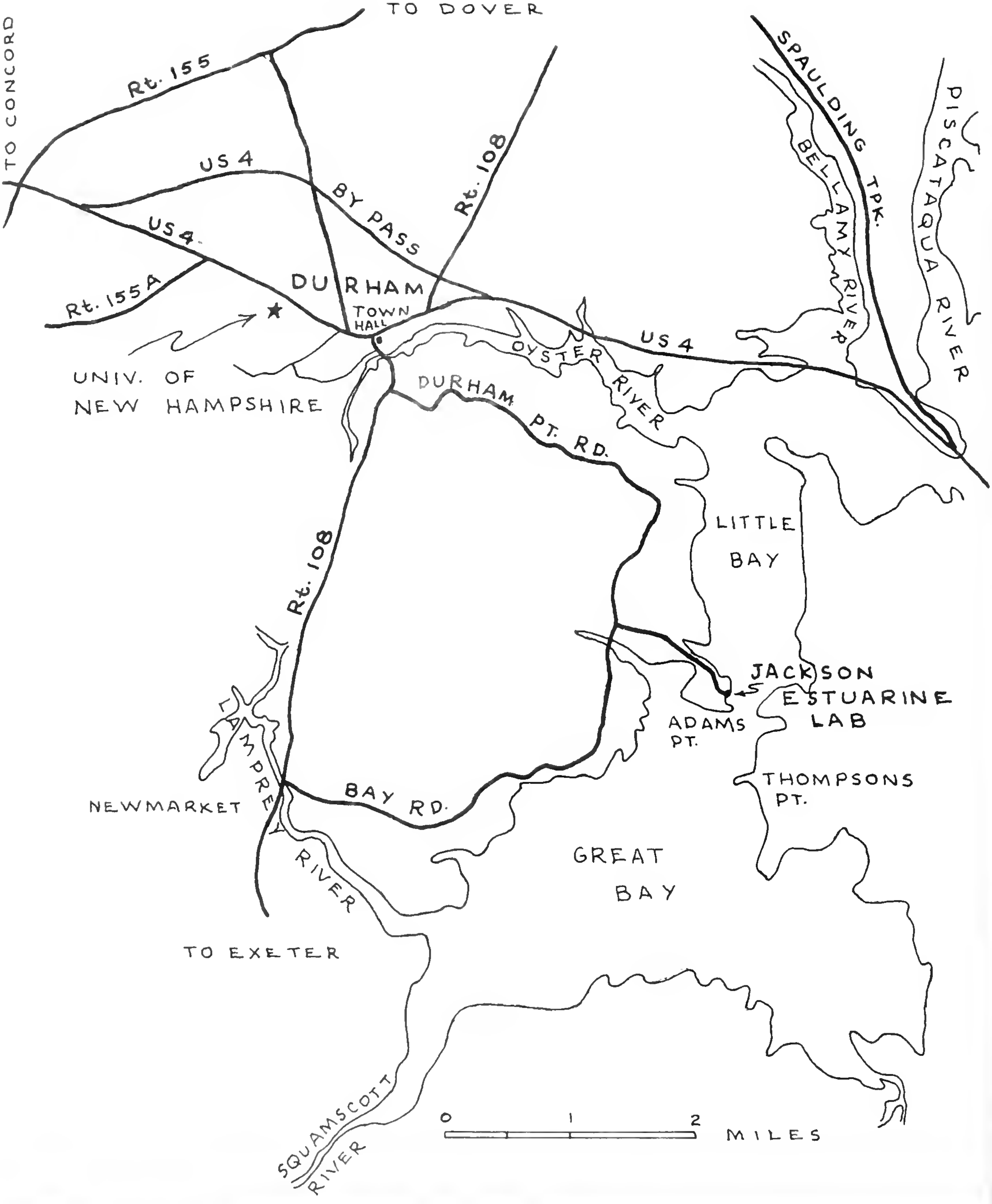
TO DOVER
TO CONCORD
Rt. 155
US 4
BY PASS
Rt. 108
US 4
Rt. 155A
DURHAM
TOWN HALL
UNIV. OF NEW HAMPSHIRE
OYSTER RIVER
DURHAM PT. RD.
US 4
SPAULDING TPK.
BELLAMY RIVER
PISCATAQUA RIVER
LITTLE BAY
Rt. 108
JACKSON ESTUARINE LAB
ADAMS PT.
THOMPSONS PT.
LAMPREY RIVER
NEWMARKET
BAY RD.
GREAT BAY
TO EXETER
SQUAMSCOTT RIVER
0
1
2
MILES

Figure I

ROAD LOG FOR TRIP B-1

Proceed easterly from Concord on Route 4 for 34 miles to the center of Durham. Trip mileage begins here, aided by map showing location of Jackson Estuarine Laboratory.

Mileage

0.0 Starting at the Durham Town Hall (Junction of U.S. 4 and Rt. 108 in town) drive south on Rt. 108, 0.4 miles.

0.4 East (left) on Durham Point Road 3.6 miles (which curves and eventually heads south).

4.0 East (left) on Adam's Point Road 1.0 miles (sign here indicating Jackson Estuarine Laboratory). Drive carefully 0.8 miles: narrow, winding road. Drive VERY CAREFULLY last 0.2 miles: single lane, narrow winding road to lab.

5.0 Park in upper lot; if this is full, drive on a few feet to lower lot.

TRIP B-2

GEOLOGY OF THE HOLDERNESS QUADRANGLE

Evan Englund
Dartmouth College
Hanover, N. H.

Introduction

The Holderness Quadrangle in central New Hampshire lies astride or slightly to the west of the projected axis of the Merrimack synclinorium. This trip illustrates problems encountered in attempting to define lithostratigraphic markers in the pelitic schists of the area, and demonstrates that the metasediments have passed through at least two, and possibly three phases of folding. Thin sheets of Winnipesaukee Quartz Diorite and Kinsman Quartz Monzonite in the northeastern portion of the quadrangle appear to play a significant role in the overall structural interpretation.

Lithology

The Littleton formation (Dl) is the principal metasedimentary unit in central New Hampshire. It consists chiefly of gray quartz-biotite schists, often with garnet and/or sillimanite. Graded sequences consisting of alternating quartzitic and pelitic layers up to 4 or 5 cm. thick are sometimes seen, as well as a similar, though somewhat thinner compositional banding with no obvious grading. Coticule bands and calc-silicate boudins are present, but the latter are relatively rare. The weathered surface is generally gray, except where pyrrhotite or pyrite is present, when the surface takes on a rusty color. The latter phase of the Littleton is sometimes difficult to distinguish from the Clay Brook member.

The Clay Brook member (Dlc) is the only mappable sub-unit of the Littleton observed to date in the Holderness quadrangle. It is distinguished by very rusty weathering, and the presence of abundant sulfides and graphite. Typical lithologies are sulfidic, graphitic quartz muscovite schist, sometimes with biotite; and a hard, sulfide-rich, quartz-feldspar granulite. Garnet and sillimanite are rare.

The Kinsman Quartz Monzonite (kqm) is characterized by K-feldspar megacrysts up to 10 cm. or more in length. These commonly have discontinuous myrmekitic rims, and are frequently rounded or tapered by shearing. The groundmass of quartz, biotite, and plagioclase often appears cataclastic in thin section. The Kinsman-Littleton contact is complex, and the contact zone (Dlk) can be best described as a lit-par-lit injection of Kinsman along the foliation of the Littleton schist.

The Winnipesaukee Quartz Diorite (qd) is a well foliated, homogeneous, medium-grained, quartz-feldspar-biotite gneiss, and is generally considered to be equivalent to the Bethlehem gneiss.

The Concord granite (big) is a generally non-foliated homogeneous, light gray, muscovite-biotite granite.

Structure

Figure 2a shows poles to foliation over the entire area of the Littleton Formation in the Holderness quadrangle. The simplest explanation for the broad girdle pattern is to assume an original, nearly horizontal (axial-plane?) foliation, refolded rather gently around horizontal NW axes to a maximum dip of about 50°, and then isoclinally refolded again about horizontal NE trending axes. Although bedding, where observed, is generally parallel to foliation, minor folds and lineations suggest that this original foliation is axial plane foliation to large recumbent isoclinal folds with NW trending axes.

This picture is complicated by the fact that the distribution of poles to foliation is not uniform throughout the quadrangle, as shown in Figures 2b, 2c, and 2d, corresponding to zones 1, 2, and 3 in the Littleton Formation on Figure 1. Note the essentially vertical nature of the foliation in zone 1, compared with the relatively shallow dips in zone 3. Zone 2 appears to be intermediate. This is interpreted as indicating that the deformation about the NE axes was of about the same intensity as that about the NW axes in zone 3, leading to relatively shallow folds, whereas in zone 1, the folding about NE axes was much more intense, obliterating most of the evidence of earlier folding.

The outcrop pattern of the Clay brook member, along with its foliation pattern suggests that it is a southerly plunging antiform. Unfortunately, this has no stratigraphic significance if an early period of recumbent isoclinal folding is assumed.

The Kinsman Quartz Monzonite and Winnipesaukee Quartz Diorite together form a pluton of batholithic dimensions, even without considering their extension to the east of the Holderness Quadrangle. Gravity measurements by Bean (1953) and Englund (unpublished data) indicate, however, that the maximum thickness of this batholith in the Holderness Quadrangle is from 2 to 4 km. Similar results have been obtained by Clark (cf. Cardigan Pluton Road Log) in the Mt. Kearsage Quadrangle. This, and the generally concordant nature of the contacts suggests that the Kinsman-Winnipesaukee pluton was intruded as a large still-like body, or perhaps formed in situ by the melting of a thick pile or piles of silicic volcanics (Thompson et al., 1968).

Figures 2e and 2f show poles to foliation for the Kinsman and the Winnipesaukee. These foliations are apparently related to the last period of deformation. The cataclastic nature of the deformation in the Kinsman indicates that it had solidified prior to this last period of folding. The Kinsman-Winnipesaukee pluton may have acted as a solid plate during this final state of folding, partially shielding the area in zone 3 from deformation, while intensifying it in zone 1.

The proposed sequence of events in this area may be summarized as follows:

1) Deposition of Littleton Formation as turbidites and pelites. Deposition ended in the Lower Devonian, but areal relations suggest that some of the Littleton(?) may be Silurian or older. The position of the Clay Brook member with respect to the Littleton is uncertain.
2) Isoclinal recumbent folding about NW trending axes, leading to a prominent horizontal axial plane foliation.
3) Intrusion of the Kinsman-Winnipesaukee "sill". Lit-par-lit injection of the Littleton occurs around the edges of the sheet.
4) Gentle open folding about NW trending axes. This may have occurred before intrusion of the Kinsman-Winnipesaukee sheet.

5) Folding about NE trending axes. More intense in zone 1 than in zone 3. Occurred after solidification of the Kinsman-Winnipesaukee pluton.

6) Intrusion of Concord granite.

7) Intrusion of lamprophyre dikes.

The time of metamorphism is uncertain, but retrograde metamorphism suggest that it is pre-Concord, and the lack of contact metamorphism suggests that it was probably comtemporaneous with the emplacement of the Kinsman-Winnipesaukee pluton.

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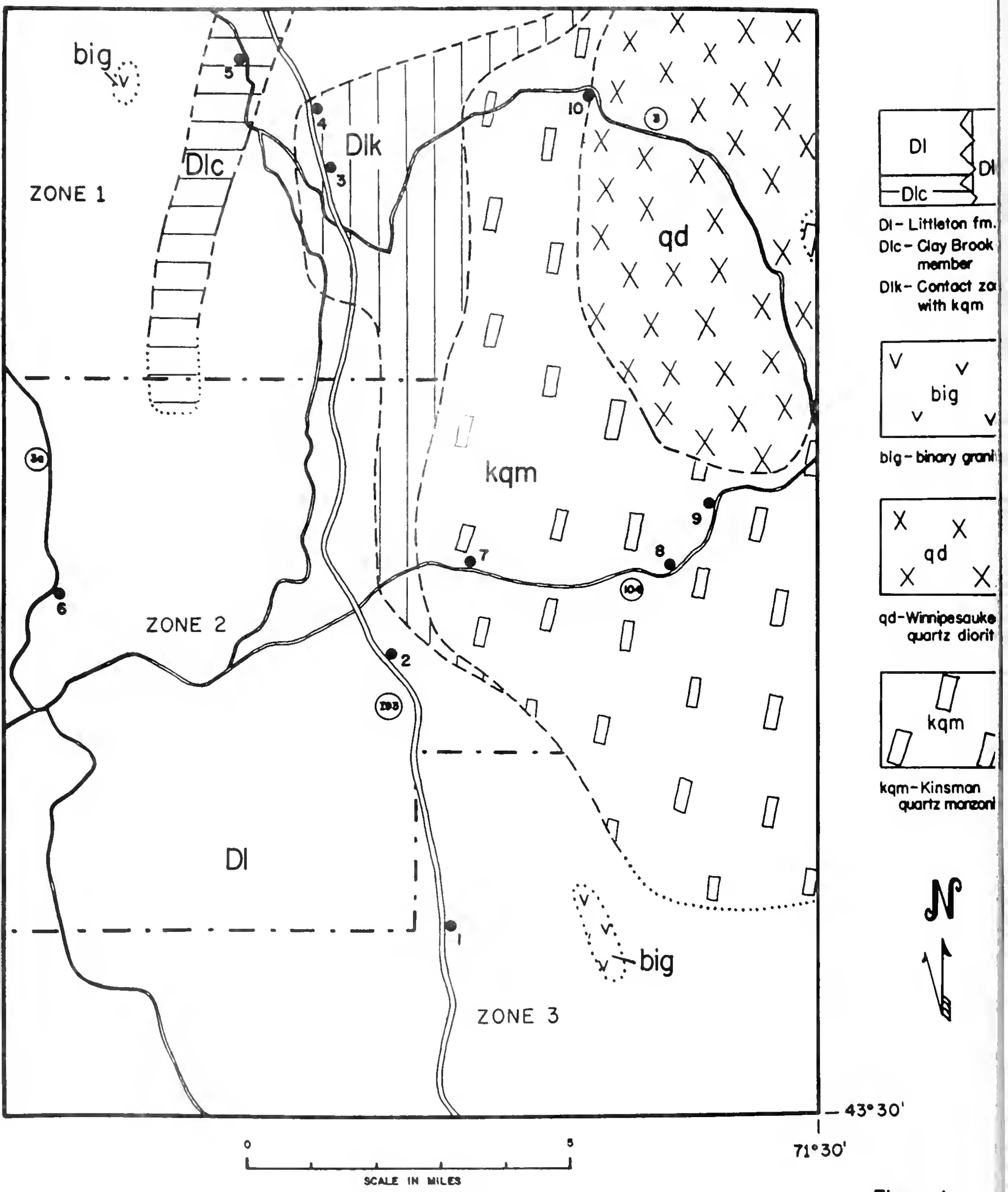
Thompson, J. B., Peter Robinson, T. M. Clifford, and N. J. Trask, 1968, Nappes and gneiss domes in west-central New England *in* E-An Zen, W. S. White, J. B. Hadley, and J. B. Thompson (eds.) Studies of Appalachian Geology, Northern and Maritime. Interscience Publishers, New York, p. 203-218.

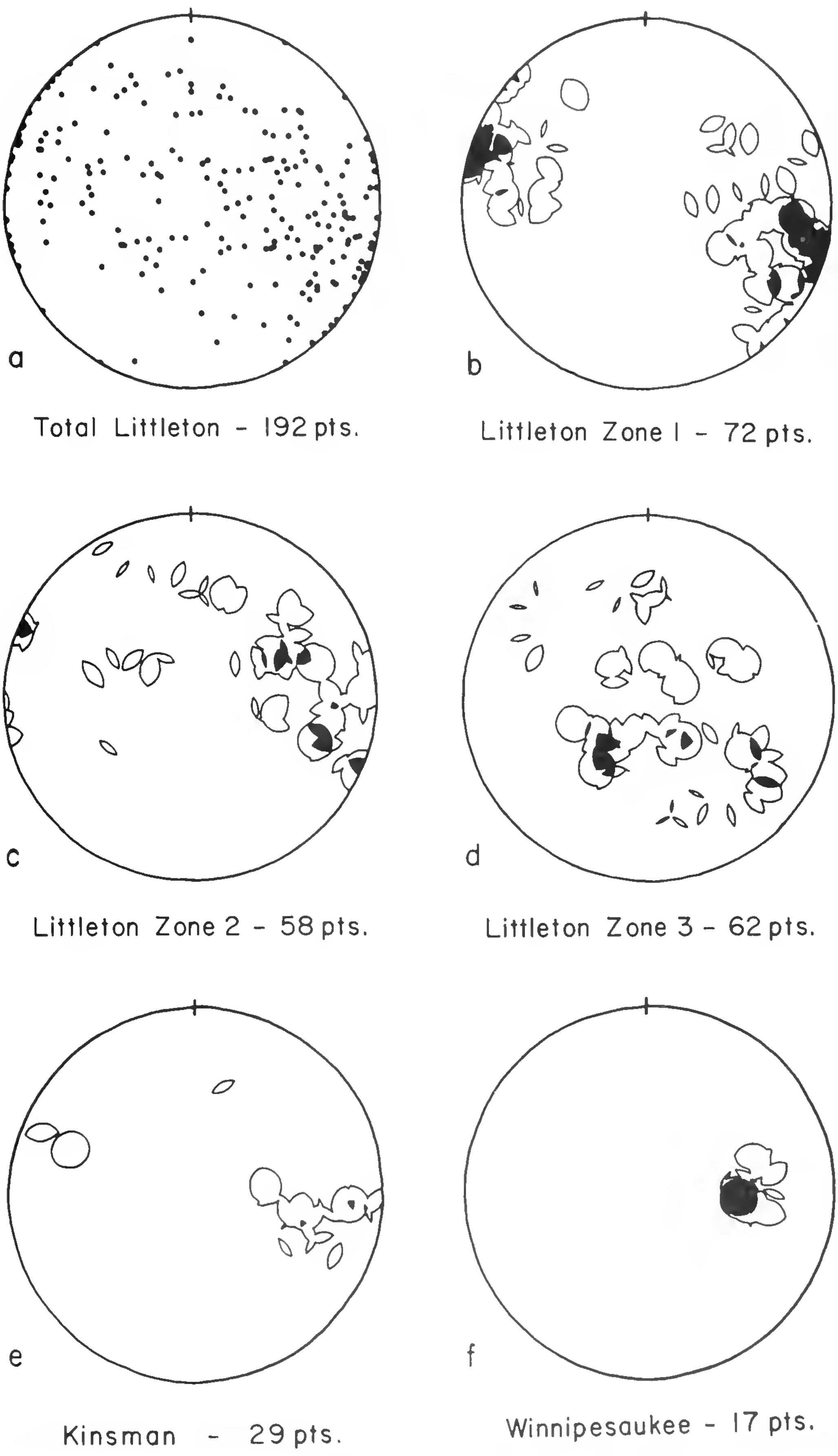
GEOLOGIC MAP
of the
HOLDERNESS QUADRANGLE, N.H.



E. Englund 1971

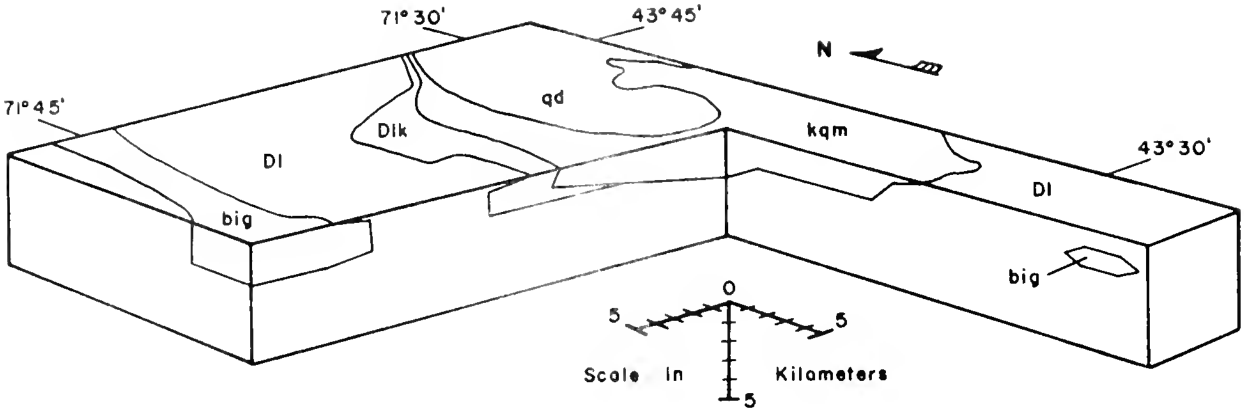
Figure I.

Equal Area Diagrams Showing Poles to Foliation



Contour Maxima: b. 4%; c. 7%; d. 7%; e. 12%; f. 20%

Figure 2.



PLUTON STRUCTURES IN THE
HOLDERNESS QUADRANGLE —
INFERRED FROM
GRAVITY ANOMALIES

big – Concord Granite
qd – Winnipesaukee Quartz Diorite
kqm – Kinsman Quartz Monzonite
Dl — Littleton Formation
Dlk – Kinsman-Littleton Contact Zone

Figure 3.

ROAD LOG TRIP B-2

Mileage

0.0 New Hampshire Highway Hotel, Concord.

0.2 Turn right on Route 9, then right (north) again onto Interstate 93.

23.7 Sanbornton exit (exit 22).

26.6 STOP 1 Littleton Formation (Dl) showing 2 sets of fold axes and lineations. Earlier recumbent folds have NW trending axes. The principle foliation in this area is axial plane foliation to this earlier period of folding, and appears to have been originally horizontal. Later fold axes trend N to NE, parallel to the regional trend.

28.3 Outcrop of Concord granite (big) on right.

29.1 Meredith Town Line.

30.4 New Hampton Town Line.

31.1 STOP 2 Sillimanitic Littleton with tight folds around NE axes. Two sets of lineations indicate earlier folding around NW axes (note garnet formation).

31.7 Exit 23.

38.2 Exit 24.

39.3 STOP 3 Littleton, partly sulfidic, with Kinsman at northern end of outcrop. Note size of feldspars in Kinsman, which are smaller here than within the main mass of the pluton.

40.3 STOP 4 Littleton and Kinsman.

42.1 Holderness Town Line.

43.2 Turn right at exit 25.

43.4 Turn right to Route 3 and 25.

44.0 Turn left on Route 3 at blinking red light in Plymouth.

45.3 Crystal Spring.

45.6 STOP 5 Clay Brook member (Dlc).

47.1 Turn right on River Road.

48.1 Continue right on River Road.

50.8 Webster farms. Lunch.

56.3 Bear right to Bristol.

57.0 Right on Route 104.

60.7 Bristol Square. Junction with Route 3A, turn right.

60.8 Bear right toward Newfound Lake.

63.3 Turn right at Cliff Lodges.

63.4 STOP 6 Banded Littleton. Synclinal fold, right-way up? Graded bedding, cross bedding, and boudins.

Turn around

63.5 Turn left on Route 3A and return to Bristol.

66.0 Junction with Route 104 in Bristol.

66.1 Turn left on Route 104 at Bristol square.

70.7 Bridge across Pemigewassett River.

71.0 Littleton Formation with ptygmatic fold axes at right angles to main fold.

71.9 Interstate 93 Underpass, continue on Route 104.

73.8 STOP 7 Kinsman showing discordant structures (foliations), shear zones and xenoliths. Notable textural relations include biotite pseudomorphous after garnet and myrmekitic rims around K-feldspars. Note - compare size of megacrysts with those seen at STOPS 3 and 4.

77.1 STOP 8 Concord granite intruding Kinsman. Kinsman shows evidence of strong deformation. East end of outcrop contains a long xenolith(?) with development of K-feldspar megacrysts. Note K-feldspars replaced by quartz.

77.4 Outcrop similar to above. Note Lamprophyre dike. Fission track ages on 5 lamprophyres of the Holderness Quadrangle average 142 ± 8 m.y.

78.3 STOP 9 Kinsman with evidence of granulation and crushing. Compositional layering with K-feldspar-rich layers suggesting filter-pressing.

80.6 Turn left on Route 3 toward Meredith.

81.6 Meredith; junction with Route 25, continue north on Routes 3 and 25.

82.1 Winnipesaukee Quartz Diorite (Bethlehem Gneiss).

85.5 Holderness Town Line.

88.5 to 88.7 STOP 10 Contact zone between Winnipesaukee and Kinsman. This is one of the few places in New Hampshire where these two units are in contact. Age relations are uncertain, but kqm may intrude wqd. Felsic and mafic dikes of White Mountain magma series cut the outcrop. Do the structures in

the Winnipesaukee suggest either a metasedimentary or a volcanic origin?

89.0 Outcrop of typical Kinsman on left.

91.1 Ashland town line.

93.6 Turn right on Route 3.

94.3 Junction with Interstate 93; proceed south on Interstate 93 to Concord.

END OF TRIP

TRIP B-3

GEOLOGIC REVIEW OF THE BELKNAP MOUNTAIN COMPLEX

Wallace A. Bothner and Henri E. Gaudette
University of New Hampshire
Durham, New Hampshire

Introduction

The Belknap Mountain complex of central New Hampshire is one of several classic ring dike complexes identified in New England. The complex is located between the towns of Alton and Gilford, New Hampshire, and lies in close proximity to several other similar and related complexes; as for example, the Ossipee Mountain complex (Kingsley, 1931), Red Hill (Quinn, 1937), and the Merrymeeting stock (Quinn and Stewart, 1941). Each complex contains rocks assigned to the White Mountain Plutonic-Volcanic series (Billings, 1928, Chapman and Williams, 1935). Rocks of this series, originally thought to be of late Paleozoic age (Billings, 1934), have been dated radiometrically between about 100 and 200 m.y., most recently by Foland *et al*. (1971) and Armstrong *et al*. (1971), a mid-Mesozoic age. The Belknap complex lies between these ages with K/Ar dates of 158 and 149 m.y. for diroite and granite, respectively (Foland *et al*., 1971).

Early geologic work in the Belknap Mountains was completed by Pirsson and Washington (1905, 1906) followed by more detailed work by Modell (1936) whose geologic map is reproduced in this field guide (Figure 1). Subsequent geologic work of a mineralogical and geochemical nature in the Belknap Mountains (Gaudette and Bothner, 1969) has contributed to the understanding of the evolution of this central complex of the White Mountain series. In recent years, additional excellent and easily accessible exposures have been made by new highway construction. These new exposures, which change little of Modell's work, do afford a better opportunity for close field examination. The aim of this field trip is, then, to examine critical exposures and to discuss the petrological and geochemical characteristics of the White Mountain rocks in the Belknap complex.

Petrology - Geochemistry

The Belknap complex contains the most complete rock sequence of any complex in the White Mountain series. Rocks range in composition from gabbro to granite and include as well as the typical syenites, vent agglomerates, intrusive breccias, and a screen of the Moat volcanics. The rocks of this complex were emplaced into the Winnipesaukee quartz diorite and Meredith porphyritic granite, both members of the New Hampshire Plutonic Series (Upper Devonian) and the Devonian Littleton Formation (Billings, 1956).

Following the designation of Modell (1936), the rock types in the Belknap Mountains are, in order of apparent increasing age (Moat volcanics excepted).

Trap syenite breccia	tsp
Rowes vent agglomerate	va
Conway granite	cg
Albany porphyritic quartz syenite	aqs
Lake quartz syenite	sqs
Sawyer quartz syenite	pqs
Belknap syenite	s
Gilmanton (augite) monzodiorite	am
Ames monzodiorite	m
Endicott (brecciated) diorite	bd
Gilford gabbro	g
Moat volcanics	mv

The age relationships are based on cross-cutting relations, "the law of decreasing basicity" (Modell, 1936), and in part by radiometric dates (Foland *et al*., 1971).

The megascopic characteristics of these rocks are discussed in the description of individual stops in the road log. The modal characteristics are, however, summarized as averages in the following table.

AVERAGE MODAL ANALYSES--BELKNAP MOUNTAIN COMPLEX

	g	bd	m	gm	s	sqs	pqs	aqs	cg
Plagioclase	49.8	73.4	49.4	42.1	35.5	29.5*	32.4	22.1	19.0
An Content	64	32	32	28	30	28	28	28	23
K-felspar	-	-	29.3	42.0	51.8	53.6	48.4	54.7	49.5
Quartz	-	3.4	5.3	2.6	4.8	13.8	16.0	13.6	28.2
Biotite	6.9	8.1	6.2	4.3	4.3	9.0	2.0	7.5	2.1
Amphibole	26.4	12.5	7.8	6.9	2.6	1.7	>1.0	1.4	-
Pyroxene	9.8	1.3	1.7	-	-	-	-	-	-
Opaques	6.7	1.2	0.4	2.0	0.9	1.0	1.1	0.3	0.7
Accessories	0.4	0.1	tr	0.1	0.1	0.4	tr	0.4	tr

(600-1200 counts were made for each slide; accessories included: apatite, rutile, allanite, fluorite, sphene and zircon. Occasional opaque sulfides are also present. Modell's modal analyses are not included in this table.)

*A small amount of nepheline was identified on Rattlesnake Island.

Geochemical data are not reproduced here. However, standard X-ray fluorescence analysis has been made for each major rock type in the Belknap complex (Gaudette and Bothner, 1969). The following elements were determined from whole rock samples: K, Rb, Sr, Ni, Ca, Cr, Si, Ti, and total Fe. Concentration levels of these elements and certain concentration ratios have suggested the presence of two magmatic trends in the evolution of the Belknap complex. The first trend begins with the Gilford gabbro and follows normally through the Gilmanton monzodiorite while the second trend includes the Belknap syenite and continues through the Albany porphyritic quartz syenite and Conway granite. The Moat volcanics occupy a middle position, very closely related to the Belknap syenite.

Geologic Structure of the Belknap Complex

The Belknap complex can be properly termed a composite pluton. Intrusion of some members of the sequence occurred along arcuate fractures related to volcanic activity and cauldron subsidence, while other members, at least from surface form, appear to have been emplaced as small stocks. Ring dikes cross-cut the Winnipesaukee quartz diorite, Meredith porphyritic granite, and Littleton formation and usually maintain steep, nearly vertical contacts from what can be seen from surface exposures. The ring dikes, however, are neither circular nor complete, as they are, for example, in the Ossipee and Red Hill complexes. Rather the dikes are arcs of elliptical rings that were either cut off by subsequent intrusive activity (e.g., aqs, m; Figure 1), or intruded into partial ring fractures (cg) probably representing incomplete cauldron subsidence. Good evidence for movement along arcuate fractures is found in the exposures at Stops 1 and 2, as well as several less accessible areas noted for the southern portion of the Belknap complex in Modell's paper (1936). For a more complete discussion of the structure of the Belknap complex, see Modell (1936).

Summary

The geologic history of the Belknap complex is similar to the histories of other ring complexes in New Hampshire, Scotland and elsewhere. Each involves successive periods of intrusion and associated extrusion in a relatively small area with rather definite changes in chemistry and rock type. Intrusion occurs along well defined arcuate fractures formed by cauldron subsidence.

In the Belknap complex, the earlier intrusions were emplaced as small stocks (gabbro and diorite), later followed by ring fracturing and successive intrusion of monzodiorites, syenite, and quartz syenites. These intrusive events were followed by a second period of ring fracturing, somewhat offset from the first, (Figure 1), and the emplacement of the Albany porphyritic quartz syenite. Conway granite was then intruded forcefully into the diorite, into a thin ring fracture on the southeast and northwest sides, and into the center of the complex as a central stock. A final period of volcanic activity is recorded in the

Rowes vent agglomerate (Modell, 1936).

Geochemical and mineralogical data from each major rock unit indicate that the White Mountain series in the Belknap complex evolved through fractional crystallization processes. Two fractional crystallization trends are suggested by the distribution of major and minor element concentrations. Geochemically, the Moat volcanics are closely associated with the Belknap syenite and thus do not represent the earliest, but rather an intermediate stage of development of White Mountain series rocks in the Belknap Complex.

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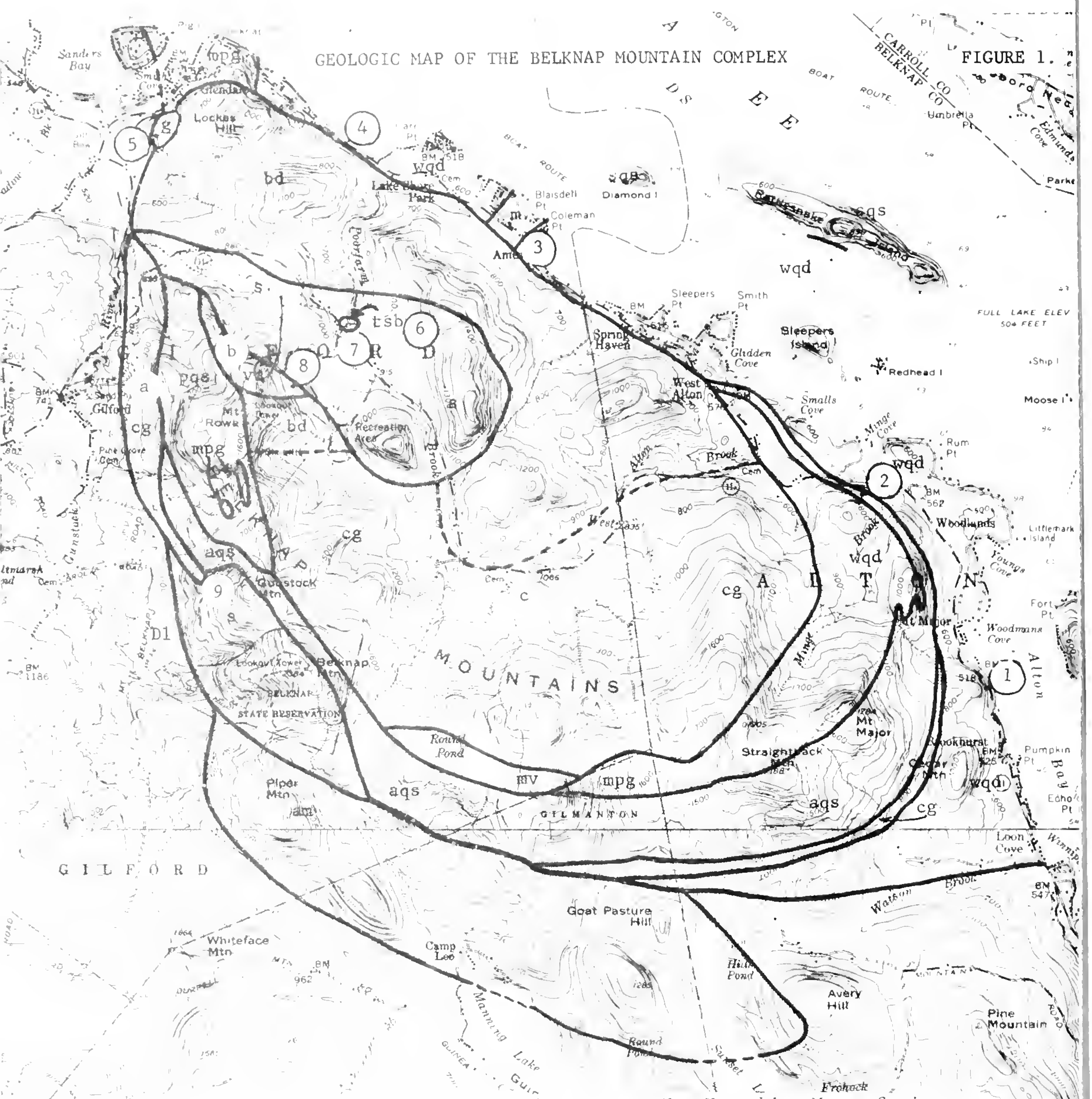
FIGURE 1.

GEOLOGIC MAP OF THE BELKNAP MOUNTAIN COMPLEX



White Mountain Plutonic-Volcanic Series

- tsb - Trap-syenite breccia
- va - Vent-agglomerate
- cg - Conway granite
- aqs - Porphyritic quartz syenite (Albany)
- sqs - Subporphyritic quartz syenite
- pqs - Pink quartz syenite
- s - Syenite (Belknap)
- am - Augite monzodiorite
- m - Monzodiorite
- bd - Brecciated diorite (w/cg)
- g - Gabbro
- mv - Moat volcanics

New Hampshire Magma Series

- wqd - Winnipesaukee quartz diorite
- mpg - Meredith porphyritic granite

Other units

- Dl - Littleton (?) formation (Devonian)

Geology after Modell, 1936

ROAD LOG FOR TRIP B-3

Participants will meet at Alton Bay, N. H. at 9 AM, Sunday morning in the large parking lot between the old Alton Bay railroad station and Victoria Pier on Route 11. The easiest route from Concord to Alton Bay is: U.S. Route 202/4 east from Concord to N.H. Route 28 (about 19 miles), Route 28 to Alton, (30 miles), and finally Route 11 to Alton Bay (2 miles). An alternate route would be Interstate 93 north to Tilton (Exit 20, 30 miles), U.S. Route 3 to the intersection of Route 11 (21 miles), and Route 11 southeast to Alton Bay (about 16 miles).

Mileage

0.0 Alton Bay railroad station.

3.1 Winnipesaukee quartz diorite (wqd) is exposed on the southwest side of the Rt. 11. Both coarse- and fine-grained phases are present in this outcrop. The coarse-grained phase contains porphyroblasts of feldspar in excess of 6 cm in length. Both are cross-cut by small felsic dikes.

3.5 STOP 1 Park in "Scenic View Area". The view to north and east consists of the upper end of Alton Bay, a large portion of Lake Winnipesaukee, the Ossipee Mountain ring complex, and finally the White Mountains in the far background. Rattlesnake Island composed of subporphyritic quartz syenite can also be seen due north in the Lake.

In the large cliff face opposite the parking area, Winnipesaukee quartz diorite is well exposed. Both coarse- and fine-grained varieties are present. The coarse-grained porphyritic wqd has large (up to 8 cm) aligned K-feldspar porphyroblasts. The country rock is cut by numerous dikes, two of which are related to the White Mountain series and were not reported by Modell. Smaller dikes are composed of diabase, granite, and granite pegmatite.

The dike on the right is a 20-foot thick green-gray quartz syenite dike trending N85W and vertically dipping. The contact with wqd is sharp with a very thin chill margin and no apparent reaction with wqd. Small phenocrysts of feldspar and round quartz grains are apparent in fresh exposure and are more visible in thin section.

The dike on the left is a strongly laminated (foliated) pink to gray syenite dike approximately 10 feet thick at road level. It trends N35E and dips about 50 SE. The contact with wqd is sharp, cataclastic, and in part mylonitic. K-feldspar clasts are often broken and rotated. Some are zoned. Quartz can be seen, particularly in the finer grained lamellae, as subround grains about 5 cm in diameter. The lamination is found only near the contacts; the center is coarser grained and more granular in appearance with occasional thicker lamellae of dense fine-grained syenite.

3.9 Mt. Major trail. Parking area on west side of Route 11. Small exposure of fine-grained wqd is exposed near the trail head.

4.5 In road cuts to the west, close-spaced exfoliation is seen in wqd. View of the Ossipee Mountains to the west.

4.9 Exposures of wqd.

5.3 STOP 2 Pull far off Route 11 in breakdown lane. Exposures on both sides of road of porphyritic quartz syenite (Albany) cross-cutting wqd. The porphyritic quartz syenite dike is part of a partial ring dike mapped by Modell (aqs). Here, in fresh exposure, it is typically pink, coarse-grained and porphyritic. K-feldspar phenocrysts are very apparent and show some zoning in hand specimen.

The contact between aqs and wqd varies in thickness from several centimeters to 2 meters. It is characterized by a black aphanitic zone some of which has been sheared to form bands of varying color and composition. The ring dike contains occasional xenoliths (wqd, diabase?) a few of which show development of K-feldspar grains. K-feldspar in aqs at the contact is set in an aphanitic matrix which grades rapidly into an equigranular center.

Several diabase and granitic dikes cross-cut wqd at this locality. The diabase has occasional irregular contacts, but contains no apparent evidence of reaction with country rock. Granitic, pegmatitic, and diabase dikes are widespread in wqd.

5.4 Intersection with Route 110.

5.5 Winnipesaukee quartz diorite exposures; rejoin old Rt. 11.

6.1 Enter West Alton, N. H.; wqd boulders.

6.4 Intersection with Rt. 11A. Small exposures along highway for the next several miles are of brecciated diorite invaded by Conway granite.

8.9 Ames Farm.

9.3 STOP 3 Ames monzodiorite (m) is exposed on the top of a small knoll very close to the road. Pull ahead of the exposure and park in the small parking area on the right, or on the small side road also on the right.

The small glacially smoothed ledge of monzodiorite is exposed on the east side of Rt. 11. Beneath the thin buff-gray weathered zone, coarse-grained medium gray monzodiorite is exposed. The fresh rock contains euhedral to subhedral plagioclase to 1 cm in length. Some of the grains have a bluish reflectance and are occasionally rimmed with K-feldspar. Some feldspar, very minor quartz, and commonly hornblende are rimmed with biotite.

Numerous small (3-4 cm) inclusions of wqd and probable metasedimentary rocks are present with thin fine-grained borders. Reaction between melt and xenolith is suggested in many places.

This unit has been mapped to the shore of Lake Winnipesaukee and appears to be continuous with quartz syenite dikes on Diamond and Rattlesnake Islands. The unit, however, is sufficiently different from sqs to warrant a separate designation.

10.5 Continue to left on new Route 11 up hill.

10.6 Small turn off on west side of road. Brecciated Endicott diorite is exposed here. Do not park here, proceed to larger turn off area and scenic area 0.5 miles ahead.

11.1 STOP 4 Scenic View area. Spectacular view of the Ossipee Mountains across Lake Winnipesaukee. Mt. Chocorua is seen to the north against a backdrop of the White Mountains.

CROSS ROAD CAREFULLY!

Brecciated Endicott diorite (bd) is well exposed in a number of outcrops along Rt. 11. The rock is characterized by abundant angular to subrounded blocks of diorite, occasional Winnipesaukee quartz diorite and probable Littleton formation. The blocks are of highly variable size, often rotated, and are separated by Conway granite (cg). The amount of cg varies considerably in short distances although there is no place along Rt. 11 where it is the dominant phase. The invaded blocks show varying degrees of reaction with the granite. Some are mere ghosts in the host granite, some have seriate edges but otherwise show no internal alteration, while others have a sharp completely unaltered character. Both fine- and coarse-grained varieties of diorite are present, some with K-feldspar phenocrysts developed within the block.

The granite is generally medium-grained, but varies depending on width of exposure. It invaded the brecciated diorite on more than one occasion, evidenced by the cross-cutting relations of granitic dikes.

12.3 Glendale, N. H. Exposures on both sides of the road approaching Glendale are of Meredith porphyritic granite (mpg). The granite here is gray, medium-grained and strongly exfoliated. It contains occasional feldspar phenocrysts and numerous inclusions.

12.9 STOP 5 Park behind the Toyota Garage on the left. Walk several hundred yards to the southwest to Lockes Hill. Gilford gabbro is poorly exposed in the pine stand and occasionally as small cliffs on the west and southwest sides of Lockes Hill. The gabbro is weathered dark gray to black in outcrop; fresh, it has a gray medium-grained character with clots of black spheroids. As Modell (1936) pointed out, this unusual gabbro contains spheroids that are composed of poikilitic brown hornblende and stand out in relief, as well as labradorite, augite, and a second green hornblende.

Contacts between the Gilford gabbro and other units are not exposed.

13.2 Junction of Rts. 11 and 11B, turn left at lights.

13.4 Turn left at Rt. 11B south, continue on Rt. 11B following the Gunstock River.

14.9 Junction with Rt. 11A, bear left.

16.3 Mt. Rowe entrance on right.

OPTIONAL STOP 6 Just beyond Mt. Rowe entrance, take left into Gunstock Acres. Be sure VISITOR CARD is visible. Drive to top of steep hill, keep to left at top (please do not sample near chalets).

Exposure of Belknap syenite and spectacular view of Presidential Range to northeast.

Belknap syenite is a coarse-grained gray syenite which weathers to a light gray to pinkish color. The exposures at the top are glacially smoothed. Good samples of this rock can be obtained in several localities in small road cuts near the stop area.

Return to Mt. Rowe entrance, park along entrance road.

16.3 STOP 7 Mt. Rowe entrance. Trap syenite breccia (tsp) exposed in stream bed of Poorfarm Brook from the bridge on Rt. 11 and downstream. This is a small probable vent area as mapped by Modell, containing fine-grained glassy "trap" (trachyte) with abundant fragments of brecciated Belknap syenite. Fragments are blocky to rounded with little apparent reaction with liquid. Plagioclase phenocrysts are common in the "trap". Petrographic character of groundmass is very similar to the coarser-grained syenite.

16.6 OPTIONAL STOP At the base lift station at the Mt. Rowe ski area, new fresh exposures of Belknap syenite have been uncovered. Fresh unaltered samples can be easily obtained at this point.

16.7 STOP 8 Rowes vent agglomerate and Belknap syenite are well exposed in an abandoned quarry just beyond the fence separating the Mt. Rowe ski area and the Gunstock recreation area. The syenite here is cross-cut by a number of dikes related to the vent agglomerate. The syenite is typically coarse-grained and contains perthitic K-feldspar up to 2 cm in length, biotite and little quartz. It is very deeply weathered and probably represents a pocket of preglacial weathered rock.

The agglomerate is quite variable in character and although it is related closely to tsp (Stop 7) it contains fewer xenoliths. Those that are present, however, are clearly defined and are occasionally quite large (2-4 m.), mostly Belknap syenite. Smaller and less frequent xenoliths of Sawyer quartz syenite (pqs), Albany porphyritic quartz syenite (aqs) and Conway granite (cg) are found. Associated dikes are dark gray, aphanitic, and contain only occasional phenocrysts and xenoliths.

17.4 Gunstock Ski Area parking lot. Assemble at the base of the chair lift and ride to the top of Gunstock Mountain (elev. 2140).

STOP 9 will consist of a geologic traverse beneath the chairlift down the mountain. The traverse starts in the Belknap syenite, crosses the Albany porphyritic quartz syenite, the Sawyer pink quartz syenite, the Conway granite and finally brecciated diorite. No unequivocal contacts between units are seen. Best exposures are of bs, cg, and bd. Sawyer and Albany quartz syenites are less well exposed.

ADDITIONAL OPTIONAL STOPS

a. Conway granite is exposed just off Potter Hill Road to the right and behind the Zimmermann Chalet in an abandoned quarry. Permission should be obtained before crossing property. The granite is fresh, pink, coarse-grained and contains quartz, plagioclase and K-feldspar, biotite, and some hornblende.

b. Rowes Vent agglomerate and Belknap syenite are very well exposed on new development roads. The roads are occasionally very steep but are passable. Take the first right on Rt. 11A from the intersection of Rt. 11B and 11A and the first right again on the graveled portion of this road; drive to the top. Outcrops are only recently exhumed by bulldozer activity.

c. Conway granite is exposed in small ledges on the left hand side of Grant Road, the second right beyond the entrance to the Gunstock Ski Area (opposite the Alberg Ski Shop and Restaurant).

TRIP B-4

SURFICIAL GEOLOGY OF THE MERRIMACK RIVER VALLEY BETWEEN MANCHESTER AND NASHUA, NEW HAMPSHIRE

Carl Koteff and Byron D. Stone_/
U.S. Geological Survey
Boston, Massachusetts

This trip will examine evidence for two tills thought to represent separate glaciations, and evidence for a minor readvance during the last glaciation. Other stops include exposures related to glacial Lake Merrimack, postlake erosion, and late glacial eolian activity.

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MAPS

Topographic maps covering the area are the Goffstown, Manchester North, Manchester South, Nashua North, and Pinnardville 7 1/2 minute quadrangles, 1968 editions, 1:24,000 scale or the Milford and Manchester 15-minute quadrangles, 1953 editions, 1:62,500 scale.

_/ Publication authorized by the Director, U.S. Geological Survey.

ROAD LOG FOR TRIP B-4

Mileage

0.0 Intersection of Interstate 93 with U.S. Routes 4 and 202 and State Route 9. Take Interstate 93 south. Road crosses the flood plain of the Merrimack River.

2.7 Junction with Interstate 89, continue south on Interstate 93. Above the flood plain the road traverses till, bedrock, and ice-contact sand and gravel deposits; the last were probably laid down in a glacial lake.

7.9 Delta on left with topset-foreset contact at 311 feet altitude. It does not fit the projected glacial Lake Merrimack profile farther south and perhaps represents a very local lake.

9.6 Hookset toll station.

15.7 Exit to Amoskeag Bridge-Goffstown; circle over Interstate 93.

16.1 Bear left at intersection and cross over Interstate 93.

16.3 Turn right on Front Street.

16.5 Lacustrine sediments exposed on the left.

16.7 Turn left on Dunbarton Road. Road ascends the Black Brook delta.

17.4 Entrance to Manchester dump on right.

STOP 1 Excellent exposures of collapse structures in Black Brook delta. The altitude of the topset-foreset contact here is 272 feet, more than 10 feet higher than the projected level of glacial Lake Merrimack.

17.4 Retrace route from dump entrance to Front Street.

18.0 Turn right on Front Street.

18.4 Turn right at intersection on Goffstown Road.

19.8 Bear left on Goffstown Road.

20.0 Goffstown town line.

22.3 Bear left on Center Street.

22.5 Turn left at intersection in the center of Grassmere. Descend steep grade to flood plain of the Piscataquog River.

22.8 Cross Piscataquog River.

23.3 Intersection with State Route 114; turn left. Road follows the southern boundary of the Piscataquog River delta which was built into glacial Lake Merrimack to the east.

24.3 Intersection with State Route 114A; turn right on State Route 114.

25.4 Intersection with Shirley Hill Road. Turn right at traffic light.

26.2 Intersection with Walnut Hill Road; continue straight ahead.

26.3 STOP 2 Exposure of lower brown till overlain by upper gray till. Color (thought to be the result of subaerial oxidation) and textural differences between the two tills and structural relationships in the contact zone are the basis for distinguishing these tills as products of separate glaciations.

Return to intersection of State Route 114.

27.1 Turn right on State Route 114. For the most part road is on top of Bowman Brook delta, which was deposited into glacial Lake Merrimack.

29.7 Intersection with State Route 101. Continue straight on Route 101 from traffic light. Road descends onto post-Lake Merrimack stream terraces.

30.7 Junction of U.S. Route 3 to Bedford.

30.9 Stop sign; turn left.

31.0 Stop sign; turn right (south) on Route 3. Road crosses several postlake stream terraces.

31.8 Cross over Everett Turnpike.

34.9 Powerline. View to the left (east) of postlake stream terraces and modern flood plain. Deposits under the powerline on the skyline across the valley are ice-contact sand and gravel deposited in glacial Lake Merrimack.

37.4 Turn left on Twin Bridge Road. Road descends over several terrace levels.

37.6 Entrance to Merrimack dump.

STOP 3 Exposure of postglacial stream-terrace deposits over collapsed lacustrine sediments of glacial Lake Merrimack. Exposure to the south is in an exhumed esker. Merrimack River and modern flood plain are to the east.

Return along Twin Bridge Road to U.S. Route 3.

37.8 Turn right on U.S. Route 3.

44.1 Intersection with State Route 101 east. Turn right.

44.3 Bear left; follow Route 101 east.

44.9 Merrimack River.

45.2 Turn off at Exit 2, Brown Avenue.

45.3 Stop sign; turn right on State Route 3A. Road traverses flood plain, exposures of Lake Merrimack sediments on the left.

46.6 Cross Cohas Brook. Road continues along Merrimack River flood plain.

49.3 Intersection with Corning Road on left. Continue straight ahead. Road ascends onto an early postlake stream terrace.

51.9 Intersection with Hillcrest Road; turn left.

52.5 STOP 4 Wind-polished bedrock locality. Outcrop is part of a silicified zone thought to represent a major fault trending northeast. Wind-cut grooves on rock show wind direction from the northwest.

Return to State Route 3A.

53.1 Turn right on State Route 3A.

54.6 STOP 4A Lake Merrimack delta exposure showing at least two incised postlake stream terraces on right. This will be an optional stop if time permits and if the exposure is in good condition.

57.5 Intersection with side road; turn right into pit.

STOP 5 Exposure in Lake Merrimack delta showing complex slump structures. Several episodes of slumping and compaction are represented.

58.2 Rejoin State Route 3A; turn right.

58.6 Intersection with Newburry Road. Turn right to Manchester Municipal Airport. Road ascends delta.

58.7 Turn right at top of hill. Road goes around south end of runway.

59.0 Bear right on Perimeter Road. Enter Grenier Field, U.S. Air Force property.

59.5 Bear left; continue on Perimeter Road.

59.9 STOP 6 Exposure on north side of road is interpreted as showing a minor ice readvance in Lake Merrimack.

60.5 Bear left (north) around runway.

60.9 Turn right through gate; cross railroad tracks.

Continue on Durgue Road.

61.3 Stop sign. Turn left on Harvey Road.

61.6 Intersection with Sheffield Road; turn right.

61.9 Stop sign. Intersection with South Willow Street (State Route 28); turn right.

62.3 STOP 7 Exposure up the hill to the right shows two tills similar to Stop 2. Complex structures occur at the contact of the two tills.

END OF TRIP. Return to Concord, north on Route 28 to Interstates 193 and 93.

TRIP B-5

IGNEOUS ROCKS OF THE SEABROOK, NEW HAMPSHIRE - NEWBURY, MASSACHUSETTS AREA_/

Andrew F. Shride
U.S. Geological Survey
Denver, Colorado 80225

Introduction

The purpose of Trip B-5 is to examine the petrographic variety of rocks that compose the syntectonic Newburyport pluton, and to compare those rocks with rather different intrusive rocks that occur south of the pluton but which have previously been considered transitional into the Newburyport. The core of the Newburyport pluton is made up mostly of medium-grained quartz monzonite and granodiorite; in the type area immediately across the Merrimack River, southwest from Stop 1, such rocks were designated Newburyport Quartz Diorite (Emerson, 1917, p. 177-178). A belt of coarse porphyritic granodiorite flanks the core rocks on the north and west, and in turn grades abruptly to light-colored gneissoid granodiorite and quartz diorite along the northern margin of the pluton (fig. 1).

The porphyritic granodiorite early was designated separately from the Newburyport, and the proposals of Emerson (1917, p. 176) and Clapp (1921, p. 24) that this rock be considered correlative with the Dedham Granodiorite have long been accepted. Only recently, Novotny (1969, p. 16) has indicated correctly that the porphyritic granodiorite is a part of the Newburyport pluton. Petrographically it has much in common with the Ayer Granite, exposed some tens of miles to the west and southwest. From structural, textural, and mineralogical comparisons, L. R. Page (oral commun., 1970) suggests that the Newburyport is of the New Hampshire Plutonic Series; he further suggests that the porphyritic part then would resemble the Kinsman Quartz Monzonite and the gneissoid quartz diorite might compare with the Bethlehem Gneiss.

_/ Publication authorized by the Director, U.S. Geological Survey

A regional fault, roughly parallel to and along Scotland Road (fig. 1), defines the south boundary of the Newburyport pluton.

Rocks south of this fault, long considered to be transitional phases between the Newburyport and the Salem Gabbro-Diorite (Emerson, 1917, p. 178), are now recognized as units with histories quite separate from either of those plutons. A fine-grained dark diorite, only superficially like the Salem and not to be equated with it, is the most widespread plutonic rock just south of the Scotland Road fault. Small bodies of a pink quartz monzonite, petrographically so distinctive as to be easily distinguished from other granitoid rocks of the region, intrude the dark diorite and its metamorphic host rocks (fig. 1). The dark diorite characteristically has borders of intrusion breccia. The more feldspathic hybrid rocks of these borders are not readily distinguished from granitoid breccias formed later where the pink quartz monzonite invaded the diorite. Feldspathized breccias associated with the quartz monzonite are the rocks most like the Newburyport Quartz Diorite, and apparently are the basis of the supposed transitional facies. Actually none of these rocks exists north of the Scotland Road fault in the quadrangles traversed during this trip.

This excursion progresses north from the Newburyport East quadrangle into the Hampton, N.H. quadrangle, turns back southward via U.S. Route 95 and ends in the Newburyport West quadrangle. Thereafter, if time permits, those interested will have the option of viewing some of the more accessible outcrops of the Newbury Volcanic Complex in the northeastern part of the Georgetown quadrangle.

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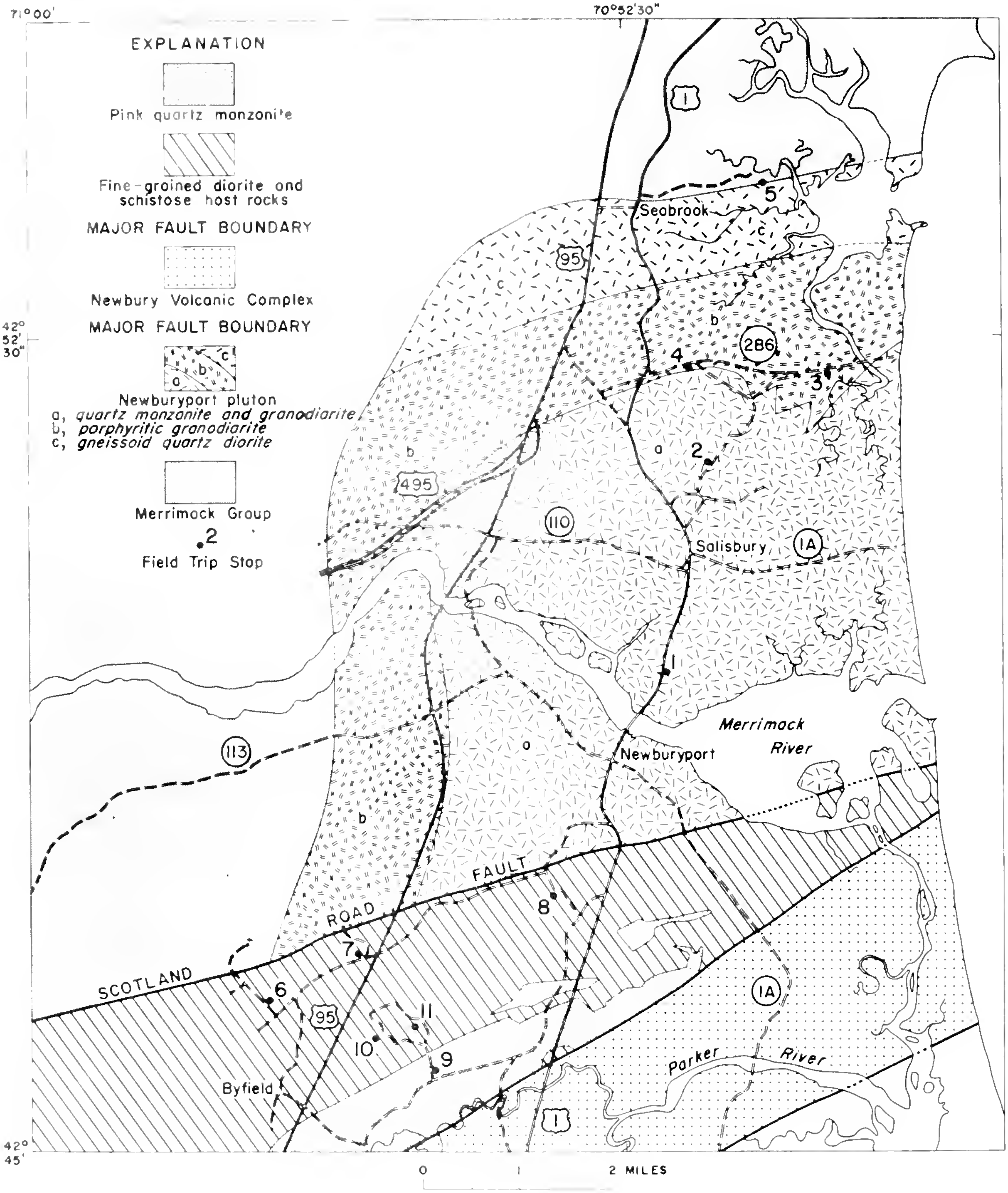

Figure 1. Rocks along route of field trip

Data incomplete; boundaries are based on recent detailed mapping and reinterpretation of older small scale maps. For units separated by faults, order in above explanation has no age significance.

ROAD LOG FOR TRIP B-5

Those arriving from Concord should leave U.S. Route 495 via the exit to Salisbury on Massachusetts Route 110. From the point of exit proceed 1.1 miles east, past the interchange to U.S. Route 95, to the first intersection with a traffic light, which is also marked by a large sign identifying the Cross Roads Plaza shopping center. Continue through the light, turn right 200 feet beyond and assemble at the north end of the shopping center parking area by 9:15 a.m.

Mileage

0.0 Start at above traffic light (junction Elm St. and Rabbit Rd.). Drive east on Route 110.

2.0 Tricky intersection. BE PREPARED TO STOP. Bear slightly left at 3-way junction and continue east on middle fork.

2.1 STOP SIGN. Turn right, with CAUTION, onto U.S. Route 1.

3.2 STOP 1 In quarry behind outcrop on left. Pull ahead 100 feet and park off road on right.
The Newburyport Quartz Diorite exposed here is perhaps midway in the narrow range of petrographic variations extant in the core of the pluton. The fabric, grain size, content of clear gray quartz and of accessory pyrite and sphene are characteristic. In the type area, 1 to 3 miles to the southwest, saussuritization is pervasive and consequently, a red and green mottling is characteristic of weathered surfaces. In the type area, completely chloritized biotite is the only mafic constituent; furthermore, the biotite occurs as euhedral books, with thicknesses 1/2 to 1 1/2 times the diameters. The rock at Stop 1 differs in that: 1) saussuritization is not as complete, 2) Mafic minerals are somewhat more abundant and include hornblende, and 3) ovoid dioritic inclusions are common rather than sparse. Here, also, only a hint of the red-green mottling exists, much of the biotite and hornblende is bright, and the biotites are not as well formed. These trends in petrographic variations will be seen to be accentuated as we move north toward the border of the pluton.

After discussion, vehicles turn around and proceed north on Route 1.

4.6 Traffic lights at junction Routes 1, 1A, and 110 in Salisbury. CAUTION, diagonal intersection. Bear toward and then to left of church ahead, on U.S. Route 1.

5.2 Intersection just short of railroad overpass--turn sharp right onto Gerrish Road.

5.6 Turn left onto Seabrook Road.

All outcrops along road are Newburyport Quartz Diorite.

6.0 STOP 2 Quarry on left. Compared with the rock at Stop 1, this Newburyport is less altered, mafic content is increased, biotite books are thinner and not as well formed, and inclusions are much more abundant. In this general area some outcrops exhibit abundant platelike schistose inclusions, aligned like great schools of fish. Ovoid inclusions may occur in the same outcrops with the platelike inclusions.

Trap dikes, such as the one in the west wall of the quarry, are especially numerous in this area but occur throughout the region. They are the only intrusive rocks that occur on both sides of the regional Scotland Road fault.

Continue north on Seabrook road.

6.5 Quarry on left. Newburyport here is still more mafic, and aligned inclusions make up a greater part of rock.

6.6 Massachusetts-New Hampshire State line. Marker on left.

7.0 Junction with South Main Street, South Seabrook. TURN RIGHT. At this point we are almost on the contact between the nonporphyritic granodiorite of the Newburyport type and the porphyritic granodiorite that will be seen at Stop 3; and we follow this northeast-trending contact along the next several hundred feet of highway. In the outcrop behind the brown house just north and to the east of the junction, a narrow 100-foot-long dike of nonporphyritic Newburyport has sharp walls against the porphyritic host rock. A similar 400-foot-long apophysis exists about 200 feet northeast of the junction. Clots of large phenocrysts occur sparsely in these dikes. In several other localities relations are reversed, in that dikes of the porphyritic rock transect the nonporphyritic rock.

7.7 Junction with New Hampshire Route 286. Islands in marsh 2,000 feet to the north and outcrops in woods 2,500 feet to northwest include metasedimentary rocks that are part of a pendant, 400 feet wide and 3,000 feet long. These rocks range from fine-grained calc-silicates (originally cherty(?) carbonate strata) to medium-grained feldspathic sandstones. Sillimanite occurs sparsely in this pendant and abundantly in other pendants within the next half mile to the north. These strata differ in lithology and higher metamorphic rank from rocks of the Merrimack Group that bound the pluton 2 miles farther north.

TURN RIGHT

7.8 to 8.0 STOP 3 Porphyritic granodiorite zone of Newburyport pluton. (Park on south shoulder, off pavement as far as possible.) On casual observation the groundmass of this variety seems similar to the Newburyport. Potassium feldspar, however, is confined almost entirely to the phenocrysts, as is brought out by weathering in these particular outcrops. Except for books enclosed in the phenocrysts, the biotites are poorly formed and in aggregates of flakes. The phenocrysts ordinarily are conspicuously twinned and 3/4 inch to

1 1/2 inches in maximum dimension -- as here, but locally are as much as 3 1/2 inches across. They may make up 35 percent of the rock, but typically make up 15-25 percent. The phenocrysts and diorite inclusions -- the latter comparable to those in the nonporphyritic Newburyport -- commonly exhibit nearly parallel alignment, as in parts of this outcrop. In this outcrop, also, we begin to see the narrow aplite and pegmatite dikes that are more abundant in gneissoid plutonic rock to the north. The porphyritic phase here occupies a belt 1 mile to 1 1/2 miles wide; transitions to the adjacent rock types are ordinarily abrupt.

Turn cars around off road at east end of outcrop, and return west on Route 286.

8.7 Road on right gives access to pendant noted at mile 7.7.

8.8 to 8.9 Outcrop on left, mainly of porphyritic granodiorite but in part gneissoid and nonporphyritic, displays mineral alignments, aplitic dilation dikes and other planar features indicative of various stresses during late stages of crystallization.

9.2 Traffic light. BE PREPARED TO STOP.

9.3 Porphyritic granodiorite on left.

9.5 STOP 4 Pass in front of Seabrook Fire Station which is on south side of highway, turn left and park in southwest corner of paved area.

First to be observed, behind the fire station, will be the variety of textural and structural features that characterize a 200-foot-wide margin of the porphyritic granodiorite. Then, on a short traverse southwest from the parking lot, the abruptness with which such material gives way to "normal" nonporphyritic granodiorite will be noted.

Continue west on Route 286.

9.6 Railroad overpass and State line. (Odometer check point.)

9.9 Turn right, 200 feet short of traffic light, and USE CARE in moving onto U.S. Route 1.

10.3 Road junction in Smithtown; continue north.

11.7 CAUTION, traffic light at junction U.S. Route 1 and New Hampshire Route 107 in Seabrook. Continue ahead.

12.0 Turn right onto Rocks Road.

(Had we continued ahead on U.S. Route 1: (1) At a point 0.1 mile beyond the turnoff and on the right are exposures of some of the intrusion breccia that will be seen at Stop 5. (2) At a point 0.7 mile beyond the turnoff, in a small outcrop on the left, is a fine-grained laminated calc-silicate rock interlayered with siltstone -- presumably the Kittery Quartzite -- that is the host rock along this perimeter of the Newburyport pluton.)

12.7 Bridge over railroad.

13.0 Outcrop on left of dark diorite that is part of intrusion breccia at Stop 5.

13.3 End of Rocks Road; continue around loop and retrace last 0.2 mile.

13.5 STOP 5 Walk along woods path to edge of marsh, 700 feet to southeast. Observe outcrops along border of marsh, then return to road via outcrops along power line 1,000 feet to the west.

Characteristic of at least the northern exposures of the Newburyport pluton is a peripheral belt of distinctive gneissoid (protoclastic) rock with definite affinities to the rocks viewed earlier. At this stop this belt is northeast trending and almost a mile wide. Along the southern margin of the belt the gneiss is transitional into the porphyritic granodiorite. There it may be granodiorite; through much of the belt, however, the potassium feldspar content is low and the rock is better described as a highly quartzose diorite. The gneissoid rock contains appreciably more quartz than the nongneissoid varieties. Lenticular aggregates of fine-grained quartz which project conspicuously on surfaces that have been exposed to salt water, and ragged flaky biotite, generally little altered, define the foliation. Hornblende is found only where the gneiss is bordered by more mafic rock or contains abundant mafic schlieren.

A traverse across the marsh in this peripheral belt is not feasible for the group. Fortunately, much of the petrographic variation to be seen on a broader scale is telescoped into a few outcrops at this stop at the border of the belt. Note especially: (1) the "quartz-eyed" gneiss, and its textural relations to inclusions and the porphytitic rock; (2) the abrupt transitions between petrographic varieties; (3) the alignments of inclusions and phenocrysts in relation to foliation and the boundaries between host types; and (4) the internal makeup of the inclusions.

On the return along the power line variations in an intrusion breccia made up largely of a more mafic diorite, which locally borders the leucocratic part of the pluton in this particular area, will be viewed.

Return to U.S. Route 1.

14.7 Turn left onto U.S. Route 1. Move to right lane as soon as possible.

15.0 Turn right, at TRAFFIC LIGHT, onto Route 107.

15.4 Leave Route 107 at second (south-heading) exit to U.S. Route 95.

15.7 On U.S. Route 95 and beneath Route 107 overpass (odometer check point).

16.1 Outcrops on right. Gneissoid granodiortie that fringes Newburyport pluton.

18.1 Off-lane to U.S. Route 495. Stay left on U.S. Route 95.

19.8 Outcrops on right are of the "core" or typical Newburyport. The rock here is especially green because it is locally sheared and is altered to a greater degree than is usual.

20.1 North abutment Merrimack River bridge.

21.4 Massachusetts Route 113 overpass (odometer check point). Outcrops readily noted within the next 1.3 miles are the porphyritic granodiorite. On the left at mile 22.1 outcrops of nonporphyritic Newburyport are visible fleetingly. For 1/4 mile in that vicinity U.S. Route 95 virtually follows a north-trending fault boundary between the two rock types. As a consequence of shattering, the rocks are much altered and the convenient roadcuts are not entirely representative of this part of the pluton.

23.8 Projected position -- closely controlled by outcrops -- of Scotland Road fault, which here strikes N. 73° E. South of this fault -- at least as traced along a length of 17 miles -- rocks of the Newburyport pluton are absent. Nor do the distinctive rocks that will be seen next exist north of the fault. Skehan (1968) has interpreted this to be the northeastern extension of the master fault of the group that he studied carefully in the Wachusett-Marlborough tunnel, 45 miles to the southwest.

23.9 to 24.1 Outcrops on left of hybrid rock, mainly fine-grained diorite, such as will be seen at Stop 7. At south end of exposure are good examples of the Triassic(?) trap dikes common in this terrane.

24.1 Leave U.S. Route 95 via exit to Scotland Road.

24.3 Junction with Scotland Road; turn right.

Will return later and park 300 feet west of here for Stop 7. Scotland Road becomes South Street beyond that point. The many outcrops farther along South Street are mainly like those to be seen at Stop 6, though some compare to those of Stop 7.

25.2 CAUTION: Traffic can be hazardous at junction. Slow at town line sign and take right fork, staying on South Street rather than the more travelled Main Street.

25.5 Junction, take right fork onto Moulton Street.

25.6 to 25.8 <u>STOP 6</u> Fine-grained dark diorite. Pull to far end of outcrop and stop as far off road as possible.

The diorite south of the fault contrasts with the Newburyport to the north in that it is much finer grained and texturally distinctive, is much darker in color and lower in quartz

content. Hornblende, euhedral and commonly little altered, is the principal mafic mineral and in places -- as at Stop 6 -- almost the only mafic mineral; some facies contain appreciable biotite. Epidote is ubiquituous along fractures and the mafic minerals are locally chloritized, but the plagioclase is not pervasively saussuritized, and the rock lacks the green cast seen through much of the Newburyport pluton. Indeed, the plagioclase, which commonly weathers somewhat opaque and orange-pink, typically is glassy on a fresh break. Characteristically the grain size, within the usual range of 0.5 - 2mm., is locally variable. Also, on a broader scale, the quartz content varies erratically; some exposures show very little quartz, others contain in excess of 15 percent.

Diorite of this character extends at least through the Georgetown 7 1/2-minute quadrangle to the south, as well as some distance west. For decades it was equated with the possibly contiguous Salem Gabbro-Diorite. Recently, Toulmin (1964) and Castle (1965) have suggested -- mainly because the Salem is pyroxene bearing and altered -- that these dioritic rocks be designated separate formations. Additional criteria for their separation are needed.

Continue northwest on Moulton Street.

26.0 Junction with Brickett Street. Make tight U-turn and reverse course along Moulton Street.

26.5 Turn left onto South Street.

26.8 Junction onto Main Street. CAUTION, watch for traffic merging <u>blind</u> from right.

27.6 <u>STOP 7</u> Park in open area on left side of road, just west of interchange. Outcrops to 1,000 feet west of Route 95 underpass may prove of interest. <u>BE CAREFUL</u> of traffic near interchange.

The fine-grained diorite is commonly bordered by intrusion breccia. Farther away many inclusions of the wall rock may contaminate the mass; these inclusions -- partly assimilated -- triggered a broader spectrum of petrographic variations than was seen at Stop 6. If the inclusions are amphibolite, not greatly different from the diorite in composition (as at the latitude of Stop 7), distinguishing between host and intrusion can be difficult. In this vicinity a petrographic variety ranging from foliated to massive and from very fine grained to coarse grained can be viewed. In outcrops along U.S. Route 95 3.5 to 3.8 miles south from this interchange more feldspathic -- and spectacular -- breccias represent a border phase between the diorite and a quartz-plagioclase gneiss.

At Stops 10 and 11 some aspects of a later-former intrusion breccia, extant where a quartz monzonite invaded the diorite, will be compared with features at Stop 7.

Continue east on Scotland Road.

27.8 Underpass beneath U.S. Route 95 (odometer check point).

28.2 Outcrops on right are fine-grained diorite comparable to those at Stop 6.

28.8 to 29.2 At 9 o'clock, and 800-1,000 feet north of road, are large outcrops of Newburyport characteristic of the type area, in that thick books of biotite are the only mafic mineral. Biotite is chloritized and feldspar is thoroughly saussuritized. Hills to right are underlain mainly by the fine-grained diorite; sporadically exposed are the metamorphic rocks -- especially amphibolites, but including some calc-silicate and quartzite units -- that are the local host for the diorite. The Chipman Mine and other silver-lead-zinc occurrences that were the sites for the Newburyport silver "rush" of 1875 are also in these hills.

The Scotland Road fault lies between these two outcrop areas, and closely parallels Scotland Road as far as we traverse it. The fault is exposed not far northwest and northeast of Stop 6, but not in this immediate area.

29.9 Turn right, onto Highfield Road.

30.2 <u>STOP 8</u> Park to left and right on abandoned railroad grade, as directed.

Numerous outcrops through several tens of acres in this vicinity are of the amphibolite and associated lesser calc-silicate and quartzite layers that are the host for the fine-grained diorite in the Newburyport West and East quadrangles. The outcrop along the grade just west of Highfield Road is typical of schist that is largely unmodified at some distance from a diorite or quartz monzonite intrusion. In the vicinity of Stop 7 this rock occurs as inclusions in the diorite.

Continue south on Highfield Road.

30.6 Junction, turn right onto Middle Street.

31.4 Junction with Boston Street, continue ahead.

31.6 Though not readily viewed here, the rounded knob on the right has a thin capping of the dark diorite irregularily penetrated at the base of the outcrop by pink quartz monzonite. Similar relations are seen in many outcrops in a belt about 1/2 mile wide southwest from here. The apophyses that finger up into the diorite (and into previously formed diorite-amphibolite intrusion breccias) along this belt trend about N. 60° E., as do long segments of the contacts that bound a 3/4-mile-wide belt of quartz monzonite that is just south of here.

Conspicuous outcrops and erratics along the next 0.6 mile are of the quartz monzonite.

32.4 Road fork, turn right onto Orchard Street. Outcrops along the next 0.7 mile reflect a resistant granodioritic border phase of the quartz monzonite, formed where abundant xenoliths (now mainly seen only as "ghosts") were assimilated. Along this interval the granodiorite separates slivers of diorite as much as 200 feet wide. This border phase lacks the pink color of the main mass and contains hornblende, which is unusual in the quartz monzonite. Atypically, also, the mafic constituents are chloritized.

33.4 Turn right onto gravel road at entrance of Newbury Wildlife Management Area.

STOP 9 Outcrop behind Massachusetts Division of Fish and Game building on right. This quartz monzonite is characterized by pink translucent feldspar, clear quartz, and bright irregular flakes of biotite. A medium-grained seriate fabric typifies about 60 percent of exposures; most that remains is porphyritic. Except where altered in faulted areas and in border phases of the sort noted under mileage 32.4, chlorite and saussurite are generally lacking. A seemingly alaskitic variety occurs widely as rusty-weathering rubble. On close examination this proves to be one of the above varieties locally somewhat granulated in and near shear zones, and is "alaskitic" only because the biotite readily leaches away.

Typical specimens of the two most abundant varieties are seen even more readily in blocks blasted from the road 700 feet farther north. If time permits, a brief stop will be made there.

Continue north into game management area.

33.8 Turn left at road fork. Although the track ahead is one-way and dirt it is adequately maintained for low-slung vehicles.

Though not obvious, for lack of outcrops along road, the contact between the diorite (to the north) and the quartz monzonite was crossed about 400 feet back, and all outcrops along the next 1/2 mile are of the diorite.

34.3 STOP 10 Pull far enough off road to permit cars to pass. Outcrops 100-400 feet west along the trail (once the site of Downfall Street) show subtle effects of quartz monzonite intrusion into the fine-grained diorite. This border phase of an intrusion breccia can easily be confused with the breccia seen at Stop 7, but the granitoid dikes and matrix here have characteristics seen in the later-formed breccias that will be viewed 1,500-2,000 feet to the east at Stop 11.

Again, good examples of the "trap" dikes can be viewed.

Return to cars and continue north along gravel road.

34.7 Turn right onto abandoned railroad grade.

35.0 Turn right off railroad grade.

35.2 <u>STOP 11</u> Park to permit passage of cars from rear.

Principal outcrop of interest is 200 feet south-southwest of this junction with "Downfall Street". It exposes a complex intrusion breccia of diorite and its host, which is in turn transected by dikes and irregular apophyses representing the quartz monzonite. Blocks in the wall just to the north along Downfall Street further illustrate the fine-grained diorite partly assimilated adjacent to the granitoid rock.

Occurrences of such mixed rocks are conspicuous to the east along the Newburyport turnpike. The presumption that these are (1) transitions between the Newburyport and the finer grained dark diorite (with its amphibolite host, once collectively regarded as the Salem Gabbro-Diorite) as well as (2) between the diorite and the pink quartz monzonite (earlier equated with the Dedham) was apparently the basis for interpreting that all were members of a consanguineous series.

35.7 Contine south.

35.8 Back at fork in road; continue ahead.

36.1 Back at Orchard Street entrance to game management area.

END OF TRIP

<u>Exit Instructions</u>

If exiting via U.S. Route 95: turn right and at junction with Central Street, 1.1 miles distant, keep right; then enter U.S. Route 95 at Byfield interchange 0.8 mile farther along.

If exiting via U.S. Route 1 (Newburyport Turnpike): turn left, retrace route along Orchard and Middle Streets to junction 2.0 miles distant, turn right onto Boston Street, and 0.2 mile farther along enter U.S. Route 1.

TRIP B-6

GEOLOGY OF THE CONCORD QUADRANGLE

William W. Vernon
Dickinson College
Carlisle, Pennsylvania

Introduction

The Concord quadrangle in south-central New Hampshire is located on the southeast limb of the Merrimack synclinorium. It is underlain by metasedimentary rocks of the Littleton formation of Devonian age and igneous rocks of the New Hampshire plutonic series of late Devonian age (Billings, 1955). The entire area is in the sillimanite zone of regional metamorphism.

Geologic mapping of the quadrangle by the author is in progress and about three-quarters completed. Reports have been published for several of the adjacent quadrangles (Heald, 1955), (Sriramadas, 1966), and (Greene, 1971).

The Littleton formation has a very complex lithology which has led to some inconsistencies in subdivisions in surrounding quadrangles. Tentative identification of lower, middle, and upper units has been made in the Concord quadrangle. The typical rock is a gray quartz-oligoclase-mica schist, often having one or more of the following minerals in varying amounts: garnet sillimanite, orthoclase, chlorite, pyrrhotite, pyrite, graphite, tourmaline. Much of the rock is more appropriately termed a gneiss with numerous varieties represented. Quartzites and lime-silicate granulites are locally conspicuous. Weathering of iron-bearing minerals in some units has made them distinctive marker horizons. Evidence of retrograde metamorphism is widespread and biotite and garnet in particular have been replaced by chlorite, and sillimanite by muscovite.

The two largest igneous rock bodies consist of the earlier Kinsman quartz monzonite and the later Concord granite. The Kinsman quartz monzonite occurs as the Weare pluton trending north-south in the western half of the quadrangle and as other small isolated bodies throughout the quadrangle. It is generally a coarse-grained, porphyritic, strongly foliated rock consisting mainly of quartz, oligoclase-andesine, biotite, and orthoclase

phenocrysts which may reach 8-10 cm. in length. The Kinsman is intricately mixed with the Littleton throughout much of the quadrangle.

The Concord pluton is the main body of Concord granite and located in the northeast section of the quadrangle. The granite is a light-gray, fine-to-coarse-grained to subporphyritic rock composed of quartz, microcline, oligoclase-andesine, biotite and muscovite. A faint to strong planar structure in the granite is interpreted as a primary flow structure and can be related to a primary fracture system. This evidence, along with petrographic considerations, suggests a mode of emplacement by multiple forceful intrusions (Virgin, 1964).

Muscovite granite occurs as small bodies and dikes in the Concord granite and as larger masses in the surrounding schists, often associated with pegmatite and aplite. Pegmatite of several generations is present but most appears to be genetically related to the Concord granite. Lamprophyre dikes are common and cross-cut all other rock types in the area.

The dominant structure in the schist is a foliation which has a variable strike to the northeast and dips moderately to the northwest. Mineral lineations on the schistosity are common and strike northwest with a gentle plunge to the northwest. Small scale faulting has been extensive but one large silicified zone, which may be a fault zone, cuts diagonally across the lower part of the quadrangle.

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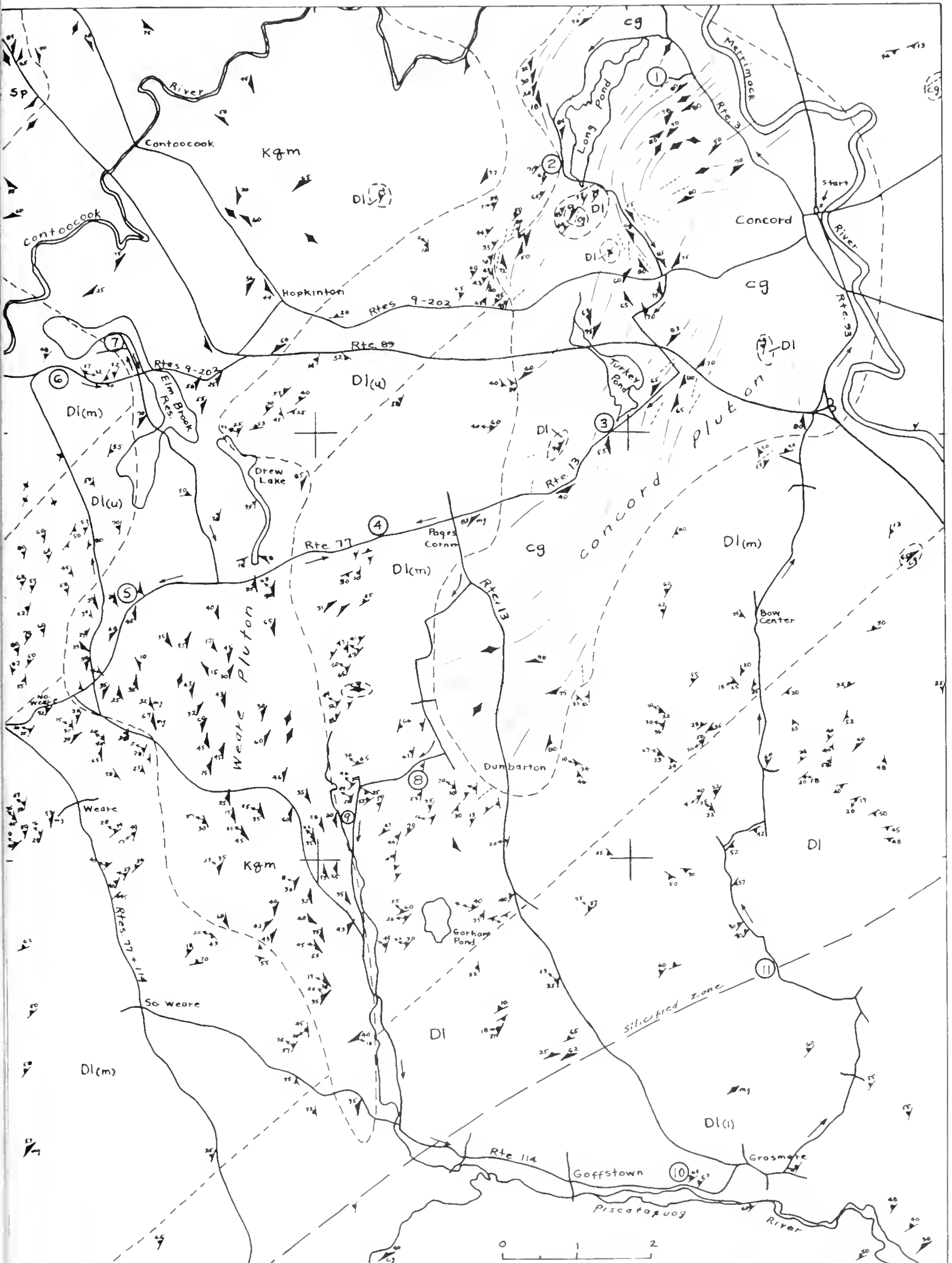

Fig 1. Geologic Sketch Map of the Concord Quadrangle

Middle-Late Devonian ?

New Hampshire plutonic series

mg

Muscovite granite

cg

Concord granite

Kgm

Kinsman quartz monzonite

sp

Spaulding quartz diorite

Lower Devonian

Dl
Dl(u)
Dl(m)
Dl(l)

Littleton formation

Dl - undifferentiated
Dl(u) - upper unit ?
Dl(m) - middle unit ?
Dl(l) - lower unit ?

70 Strike and dip of foliation

10 Strike and plunge of mineral lineation

70 Flow structure - Concord granite
mg - muscovite granite
Kgm - Kinsman quartz monzonite
sp - Spaulding quartz diorite

Trace of planar flow structure

Inferred contact

3 Field Trip Stop

Fig. 2. Legend for geologic map of the Concord quadrangle

ROAD LOG FOR TRIP B-6

Assembly: 8:30 A.M., Sunday, October 3, at Highway Motel.
Topographic map: Concord, 15'.

Mileage

0.0 New Hampshire Highway Motel, Concord, N. H. Proceed northwest on Route 3 (North Main Street).

3.0 STOP 1 Swenson Granite Works in the Concord granite.

Brief explanation of quarry operations by Mr. David Swenson. Note joints and planar structure in the granite. Is this a primary flow-fracture system similar to examples cited by Balk (1937)?

Follow Route 3 to West Concord. Turn left on Hutchins Street (0.65 mi. from quarry). Follow to Lake View Drive and go south onto Long Pond Road.

6.5 STOP 2 Contact between Concord granite and Littleton formation (middle unit?).

This is the only known exposed contact between the pluton proper and the Littleton formation. The granite is essentially concordant with the schistosity here which strikes approximately N 45°E and dips 55°NW. A strong planar structure in the granite can be seen along the road several hundred feet south of this point. Faint grooves across the top of the outcrop trend S 18° E. Glacial striae?

Proceed southeast along Long Pond Road and turn south on Fisk Road.

7.7 Hopkinton Road (Routes 9 and 202). Turn left for a few hundred feet and then turn right through St. Pauls School grounds to Silk Farm Road. Turn left and follow to Clinton St. (Rte. 13). Turn right.

11.8 STOP 3 Concord granite.

Joint sets and flow structures are well-displayed in this outcrop. Pegmatite and aplite dikes are numerous and show preferred directions. Are they related to a primary fracture system?

Proceed southwest on Route 13.

14.6 Pages Corner. Intersection of Routes 13 and 77. Follow Route 77 southwest.

15.5 STOP 4 Littleton formation.

Schists and gneisses of the middle unit (?) cut by biotite granite, pegmatite, aplite and lamprophyre. The rusty weathering quartz-pyrrhotite-rich gneiss is a key unit in the quadrangle. It is identifiable with a

"rusty quartzite" unit found in other quadrangles and placed at a lower-middle to upper-middle horizon. It is placed in the latter horizon here. Discussion of correlation problems.

The garnetiferous biotite-muscovite-sillimanite schists are usually associated with the rusty weathering unit.

Mineral lineations here strike approximately N 60° W and plunge 10-20° to the N.W. Significance?

Proceed southwest on Route 77.

18.9 STOP 5 Kinsman quartz monzonite.

This is the typical coarse-grained porphyritic Kinsman of the quadrangle although local variations are widespread. Toward the west end of the outcrop the amphibole content increases significantly. Are all the rock variations here phases of the Kinsman?

20.4 Turn right on Shaker Hill Road. Proceed north and then east on Route 9 and 202.

25.9 STOP 6 Quartz diorite.

This is the oldest member of the New Hampshire plutonic series in the quadrangle. The author equates it with the Spaulding Quartz diorite in the Monadnock quadrangle although other names have been used for a similar rock in other quadrangles. The rock is generally foliated and has a characteristic mottled effect because of the uneven distribution of biotite. An interesting problem is the explanation of the mixed light and dark colored units in the outcrop.

Follow Routes 9-202 east.

27.0 Turn left on Stumpfield Road.

STOP 7 Lunch

Go back to Routes 9-202. Cross and go south on Stumpfield Road to Sugar Hill Road North (resume mileage at crossing).

30.2 Turn left on Route 77 and return to Pages Corner. Turn south on Route 13.

31.0 Turn right.

32.5 Bear left.

33.9 Turn right on Everett Dam Road.

34.5 STOP 8 Littleton formation (lower part of middle unit?)

The unit is primarily a garnetiferous biotite-sillimanite schist and gneiss striking northeast and dipping to the northwest. Minor flexures have fold axes trending to the northwest.

Proceed westerly and bear left past entrance to dam.

35.9 STOP 9 Littleton formation (lower part of middle unit?)

This large cut in the spillway of Everett Dam shows the complex relationships between the Littleton and a variety of intrusives. Raymond Cliffs, directly west of here, is near the southern end of the Weare Pluton (Kinsman quartz monzonite).

Proceed south.

37.4 Turn south on Route 77 and proceed to Route 114.

40.1 Turn left on Route 114.

42.6 Go straight through Goffstown. Stay north of river.

44.1 STOP 10 Littleton formation (lower unit?)

This unit is a coarse-grained garnetiferous mica-sillimanite schist commonly with quartzo-feldspathic layers and pods. Large sillimanite knots on some foliation surfaces largely have been altered to muscovite. Drag folds and ptygmatic folds in quartz are common in this unit. Tourmalinization of the schist is also more widespread here than in other parts of the quadrangle.

45.8 Proceed west through Grasmere. Turn left on Tirrell Road.

47.5 Intersection. Go straight.

48.4 Turn left.

49.9 STOP 11 Silicified zone.

This is typical of the many silicified zones in this part of the State and may be the largest in the quadrangle. It is approximately 100 feet wide at this point and may be followed in a southwesterly direction, varying greatly in width. Faulting is common along these zones, but to what extent this area has been affected, if any, has not been determined.

END OF TRIP

Proceed north through Bow Center and back to Concord.